# METALS & ALLOYS

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Devoted to Engineering Metallurgy

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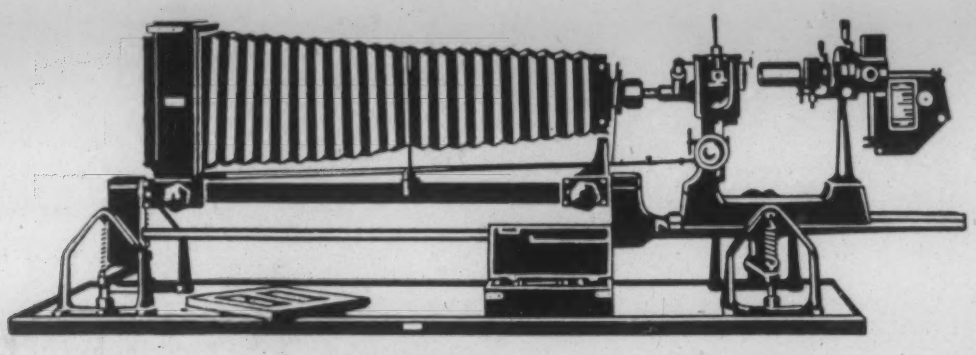

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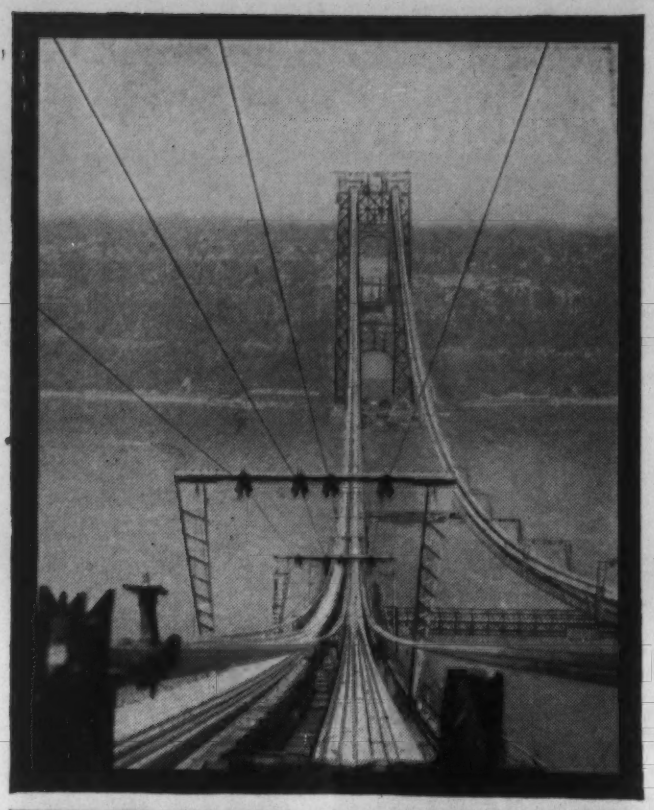
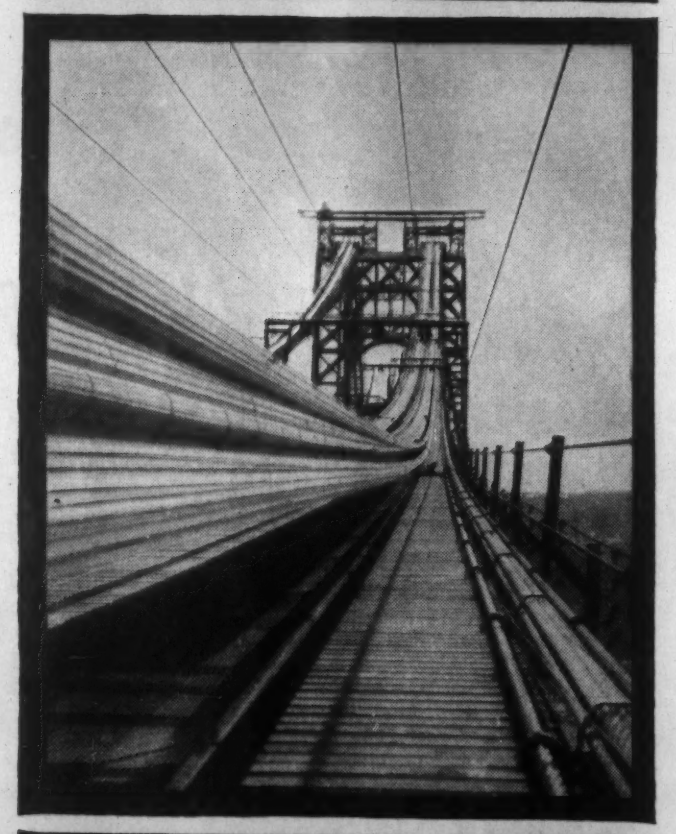




# Horse Head *Uniform Quality* Zinc on the Hudson River Bridge

It was Horse Head Zinc galvanizing on the first great suspension cables — Brooklyn Bridge; it is Horse Head Zinc galvanizing on the newest and greatest bridge cables — The Hudson River Bridge.

Horse Head Zinc's uniform quality has stood staunchly behind the development of these huge projects.

Horse Head Zinc was used on these bridges, among others:

- Brooklyn Bridge
- Delaware River Bridge
- Bear Mountain Bridge
- Mt. Hope Bridge
- Ambassador Bridge
- Mid-Hudson Bridge
- Hudson River Bridge

Specifications
for the Hudson River Bridge
*as furnished by*
*The Port of New York Authority.*

| | |
|---|---|
| Length of Bridge | 4,760 ft. |
| Span | 3,500 ft. |
| Feet above water | 250 ft. |
| Number of Cables | 4 |
| Diameter of each | 36 in. |
| Number of wires in each | 26,474 |

Weight of Zinc for Galvanizing
1,700,000 lbs.

## The New Jersey Zinc Company

160 Front Street New York City

# EDITORIAL COMMENT

## Metallic Towers

Our cover shows the Empire State Building almost completed. This is the tallest structure of any kind in the world. It rises 85 stories above the street and extends two stories below grade. It rises 1048 feet from the street to the roof of the 84th floor not including the observatory roof above this level or the mooring mast extending 200 feet higher, a total of 1248 feet. The steel frame weighs in excess of 46,000 tons; the largest single steel order ever placed for building construction. Loads on individual columns are in excess of any previously constructed similar building; several columns have over 10,000,000 pounds per column or more than 5000 tons.

The exterior masonry is Indiana limestone and granite with strips of austenitic "18-8" extending from the sixth to the 85th floor. The mooring mast rising above this is built of steel encased in aluminum and glass. The entire mast will be illuminated at night both by flood lighting and interior illumination. There are 62 elevators, not including special elevators for particular purposes. These are signal control, self-leveling elevators. Express cars reach the 60th floor in less than one minute. "Tower elevators" operate from the 80th floor to the 85th, while another elevator rises up the mooring mast to the observatory.

The building is estimated to house 20,000 people as tenants, not including individuals temporarily in the building.

At the recent annual convention of the American Institute of Steel Construction, President Charles N. Fitt predicted that tall buildings will soon be made with walls of steel instead of masonry. To many builders, the use of alloys for walls may offer attractive advantages. All-metal buildings may be more durable. To the public, metallic towers may present more striking exteriors, flashing like mirrors in the sun or gleaming in a night sky pierced by pencils of light.

Beauty in architecture is something else, however; it does not depend for effects on flashes and gleams. Nor does it spring solely from impressive height. How beautiful an all metal facade may appear will depend on the designer. This, Mr. Fitt had in mind when he said: "We must recognize the aesthetic possibility in what we construct if we are to win popular approval of our efforts."

New materials inspire new forms and modify conceptions of beauty. That masonry ever will be entirely abandoned is beyond present belief; that it may be combined with metal in exteriors of greater beauty is more probable. Beauty lies not in the tools of construction, but in the creative mind of the designer who decides what the tools shall assemble.

## Where The Heart Is

Just because you have a research problem that requires the application of a certain branch of knowledge, and you have, or have access to, an expert in that branch of knowledge, doesn't mean that you will necessarily get the answer to the problem. One other thing is required—the active interest of the expert in the particular problem. One is never as interested in other people's children or other people's problems, as in his own.

It is often more effective in the attack of a problem to have it handled by a worker relatively ignorant of the special means by which it must be solved, but one with a burning desire to get the answer, and with persistence enough to wring from the expert the broad outlines of how to apply that special means, than to hand over that phase of the problem direct to the expert.

There are research organizations—in industrial, governmental and university circles—that are full of experts and also full of regulations and traditions as to jurisdiction. It would be at least a breach of etiquette, in a problem heading up under a chemical group but requiring an excursion into electrical engineering, for the chemical group to get busy on the electrical end of the problem. It must be turned over to the electrical group, who will probably view it as a nuisance because the problem did not originate in its own cubby hole, and who will, at such time as it does not interfere too much with its own projects, give it a minimum of cursory attention. This is about like a ruling that only stenographers may use pencils.

If each problem, wherever it heads up, can be considered as a sort of family affair, and if the different groups are not jealous of anyone but themselves playing with their own speciality, but will instead let the other groups cross the lines and give them help and guidance, that research organization will go faster and farther.

Indeed it often turns out that the amateur in a field, since he doesn't know that a thing can't be done by a certain method, rushes in where angels fear to tread, and finds it can be done because he is so enthusiastic he doesn't give up. Of course, unless he can get counsel from the expert, he is likely to flounder around learning the fundamentals, and thus waste time, but expert counsel plus enthusiasm are better than actual experience plus a lack of enthusiasm.

We are moved to these comments by having sat in at a meeting of a young and enthusiastic technical committee of one of the scientific societies, where a group concerned with certain non-ferrous alloys were rarin' to go ahead on the collection of information and on experimental work in their line. Some of the projects discussed involved the application of ferrous alloys and of non-metallic materials to the production and final utilization of the particular alloys covered by the name of the committee. Since there were other committees of the society charged with dealing with the ferrous and non-metallic materials in question, problems of jurisdiction at once arose. Now these other committees have no direct responsibility for, or interest in, these particular non-ferrous alloys, and problems arising from the difficulties of the non-ferrous man would certainly be a side-show and not the main tent to them. Certainly the way to get results in such a case is to let the enthusiasts go ahead, and provide for coöperation and advice of the other committees to help steer them into the less rocky channels, rather than to insist on jurisdictional etiquette.

"Where your treasure is, there will your heart be also." And the people to handle a research project are those who are vitally concerned with the success of the project, and who do put their hearts into it.

## Patents Again

We dealt editorially with the patent situation in our February 1930 issue. Several interesting discussions of the subject came out about the same time. In the February 1930 issue of *Mining and Metallurgy*, W. E. and K. W. Greenawalt had an article on "A Plea for a United States Court of Patent Appeals." They approve of the patent system, terming it "one of the greatest humanitarian movements in the history of mankind," and direct their attention to a possible betterment of patent litigation.

In the February 1930 issue of the *Journal of the Society of Automotive Engineers*, there was an extremely interesting discussion of the methods used by automobile companies in dealing

with inventors. That discussion brings out one useful function of the patent system, as an inventor with a worthless idea who hasn't yet made a patent application, is told that he will have to make one before the company can consider it, and then the burden of dealing with the inventor is transferred to the Patent Office. The general trend of the discussion was to the effect that all the companies go through a lot of waste motion in considering inventions, and near-inventions, because there may be one grain of wheat in a barnyard full of chaff. The ratio is said to be something like 1 in 6000. The Patent Office came in for criticism, but unscrupulous patent attorneys got more.

In an authorized interview with Edison in the September 27, 1930, *Saturday Evening Post*, Remsen Crawford quotes Edison as saying that he has taken out 1180 patents, which have cost more than they have returned in royalties. Edison made money through manufacture and sale of his products, not as an inventor.

Edison suggests taking the whole patent business out of the regular judicial system, and setting up a special court with scientist judges, before whom he thinks lawyers' quibbling would be reduced. At present, he feels that a sharp lawyer can make a non-technical judge believe that black is white.

The situation has been recognized as bad for a long time. Crawford quotes a statement by Benjamin, a patent solicitor, who said in the *Electrical Review* in 1901, that while patents have been of distinct value in developing the scientific side of the electrical industry, they have been a detriment to the industry on the commercial side.

One comment on our previous editorial, which is published in this issue among the letters to the editor, questions the efficiency of the "invention department" of large corporations. There may be something to the point raised, but from what we have seen of lone wolf inventors versus corporation inventors, it seems to be the former class that as a rule devise half-baked, unworkable schemes which they then try to market before the ideas have been taken past the paper stage, while the corporation invention has as a rule been proven out in the laboratory, and is something more than a guess. Even cubs, as long as they are in laboratories, may evolve more of value than the lone inventor with nothing but a pencil. We might remember that Edison has had a laboratory.

The only way the average individual inventor can manage to try out his brain child to find out whether it is really good for anything, is to be grub-staked to laboratory facilities. Personally, we'd rather grub-stake the average mining prospector than the average individual patentee.

Some of the other comments received on the previous editorial bewail the predatory attitude of big business, apparently because of differences of opinion between the writer of the comment, as the inventor, and of the corporations approached as to the value of the invention. The metallurgical industries do not appear to us to be very predatory. We have often been astonished at the willingness of some of the big steel companies to pay royalties on rather weak patents covering processes that have been quite independently worked out by the companies, if only the patentee can show a fair trace of evidence that his conception antedated their use of it. Notorious cases of hold-ups, like those where an alleged inventor takes the chemistry taught him in college, draws up a patent application involving it, and keeps the application in the Patent Office for some fifteen years before the patent issues and the industry is approached to pay royalties on processes hoary with antiquity, may be fought as vigorously as such a case deserves, but when an inventor approaches the steel people with clean hands, they as a rule, lean over backward to treat him fairly.

We are still unconvinced that the patent system is a benefit to the country as a whole, yet we should give the devil his due. There is one useful by-product of the patent system. It is a source of mirth and gayety. The *Congressional Record* is often described as the country's funniest publication, but the *Official Gazette* runs it a close second.

One interesting patent covered a pronged attachment to put on the legs of your neighbor's hens, so that when they scratched, it dug in, and propelled the hens along so that they scratched themselves out of your garden.

Most of the joy in reading these patents comes from the fact that the patentee is so deadly serious. We recall but one case when any patentee ever showed a sense of humor. That patent related to plugs for bait-casting. The plug was provided with inset mirrors, the idea being that when the fish saw its image in the mirror, he rushed to take the bait before that other fish could get it. The discussion went on to state that if the fish were a female, the attraction of a mirror would be obvious, while in the case of a he-fish, his pugnacious instincts might be roused. However, if one suspects the fish of cowardice, one may use a reducing mirror, so that the image appears to be that of a smaller fish. As far as we know, that plug has not appeared on the market, but if it does, we shall buy one.

# READERS' COMMENTS

To the Editor of Metals & Alloys:

Your editorial, Heresy in opening on patent conditions opens on something with about as wide and varied influences as the tariff. This range of influence may be one reason for little concerning invention and patents getting into print except such as deals with some legal aspect or results of litigation.

The patent institution, like all others, has its advantages and disadvantages. And what is advantage to one organization or individual may be hurt to another. Patents involve invention. Invention means change. Capital that is already earning well, does not want change as a rule. Hence cold-storage patents. Idle capital desires change. Hence litigation. Corporations play for control and monopoly. Hence the tip to like minded individuals to attempt to gain by nusiance patents.

Man is an imitative animal. The racketeer is but a crude imitation of the hard-boiled captain of industry. The best way to eliminate the nuisance patent is to begin at the top with examples of broad vision and generous procedure. The patent situation is but surface evidence of industrial conditions. It is not a primary cause of unsatisfactory conditions. It is worth considering that where the predatory instinct is in control elimination of a patent would not eliminate the idea as an object for interference and strife. Hence business warfare would still exist.

It is not fair to blame the patent office for the results of predatory instincts masquerading under the garb of successful business ability. Probably the last great event in the history of man will be the birth of industrial peace. Till then great camps financially armed and constant, foolish warfare, except for intervals when some feudal financier gloats over his supremacy oblivious of eventualities.

What would happen to invention if the patent office were abolished, is not difficult to vision. The need of incentive to inventors is still just as essential as to Wall Street. Corporations try to get around this situation by herding into laboratories such "cubs" as your editorial speaks of as occupying the patent office, and trusting to natural tendencies for some creative mind to do something obstetric.

A corporation will pay as much as a million to an outsider for a patent which it thinks it needs, and then feed the following line to its employees: "Bonuses for inventions, or other conspicuous recognition of industrial achievement, are fatal errors; meritorious work should be recognized in salary only."

That statement, let it be emphasized, is not a translation from the German. It is from an American periodical of high repute. It seems to refute your editorial as to how industry would treat the inventor if he had no patent office. Furthermore, present-day salaries of technical workers disclose what sort of consideration the inventor may expect from industry when operating under no control.

One reason why as an incentive to invention patents are coming apparently to fall short more and more is because most corporations want not only all patents assigned to themselves but they chart the allowable course for employee inventors. Whether the directors of a few mergers are qualified to control and to direct the creative genius of the country, is a question of deep significance to our industrial progress. Furthermore, anyone who thinks the practical inventor on a salary works the same as one in his own shop, hasn't the vision required for leadership. Some engineers believe our big organizations aren't doing much big, original work.

(*Continued on page 8*)

# HEATING FOR FORGING

By Robert M. Keeney*

Forging is an operation involving heating to the plastic state, hot working and cooling of a metal or alloy for the purpose of obtaining a certain shape containing desirable properties. Heat treatment is an operation or combination of operations involving the heating and cooling of a metal or alloy in the solid state for the purpose of obtaining certain desirable conditions or properties. Forging may be defined in almost the same words as heat treatment. It differs from heat treatment only in that the stock is heated to a plastic condition, involves mechanical working, and completion occurs at or above the critical range rather than below it.

For forging, steel is heated to soften it for shaping, and worked into the desired shape while cooling so that work is completed as near the critical range as possible. Forging of steel involves both heating and cooling, just as heat treatment, and deeply affects the structure of the steel and its physical properties. It must be regarded as a heat treatment operation, if the finished product is to be a quality product, and not simply as a forming process. Heat treatment begins with forging.

Production of a quality forging involves:

(1) The use of steel suitable for forging.

(2) The application of heat uniformly to the entire surface of the stock.

(3) Heating the stock in an atmosphere tending to eliminate excessive scaling, at the proper rate to the minimum temperature necessary for softening with due consideration to the character and mass of the steel, the shape of the piece and the capacity of the hammer or press.

(4) Holding the stock at the correct temperature for the period of time necessary for complete saturation, in an atmosphere tending to eliminate excessive scaling.

(5) Working the stock into shape at a rate such that the forging is finished with its temperature as near the critical range as possible.

The fundamental principles of heating for heat treatment apply in heating for forging. Failure to follow these fundamental principles may result in undesirable qualities in the forging, which cannot be corrected or can only be corrected with difficulty, at an increase of over-all costs, by heat treatment subsequent to forging. Overheating, driving at too fast a rate, or non-uniformity of heat application result in a hot surface, but a cold interior. Overheating may cause "burning" or the formation of voids around the crystal boundaries, which may result in failure during forging or produce a coarse crystalline structure contributory to failure during service. An oxidizing furnace atmosphere causes excessive scaling. Failure to adjust the initial heating temperature and the rate of forging, so that working is completed considerably above the critical range, results in a coarse structure, or if working is completed below it, distortion occurs.

The necessity of considering forging as a heat treating process is demonstrated by the experiments of Bullens,[1] Table I. The first six tests indicate a wide variety of forging methods; some of the fractures were granular and showed "fire," some were "dead," and all showed severe overheating. Test No. 7 was properly forged resulting in a perfect cup and a large reduction in area. All test pieces were subject to the same amount of working.

**Table I—Physical Properties Vary with Method of Forging**

| Piece No. | Tensile Strength lbs./in.² | Elastic Limit lbs./in.² | Elongation in 2 in., % | Reduction of Area % | Fracture |
|---|---|---|---|---|---|
| 1 | 88,000 | 50,500 | 14 | 28.5 | Angular; dead |
| 2 | 80,500 | 50,000 | 11 | 13.5 | Burnt |
| 3 | 96,750 | 55,750 | 22 | 41.9 | Dead; half cup |
| 4 | 86,000 | 51,250 | 27.5 | 39 | Dead, angular |
| 5 | 85,750 | 51,750 | 22 | 34.1 | Granular |
| 6 | 95,900 | 54,000 | 12 | 36.5 | Granular |
| 7 | 81,650 | 54,000 | 32.5 | 65 | Silky, full cup |

## THE FUNDAMENTALS OF FORGING

To obtain the proper grain size in the finished forging, there must be coördination of the initial heating temperature, the rate of working and the finishing temperature, so that work is completed as close to the critical range of the steel being worked as possible. This is evident with an understanding of Fig. 1.[2] The solidification range and the critical range are each indicated by two parallel horizontal lines. Each diagram represents the effect on grain size of different adjustments of initial heating temperature, rate of working and finishing temperature. The widths of the shaded areas of the diagrams are relatively proportional to the grain size resulting from the various treatments. Where the area is reduced to a line, the corresponding grain size is very small, that is, the structure is very fine.

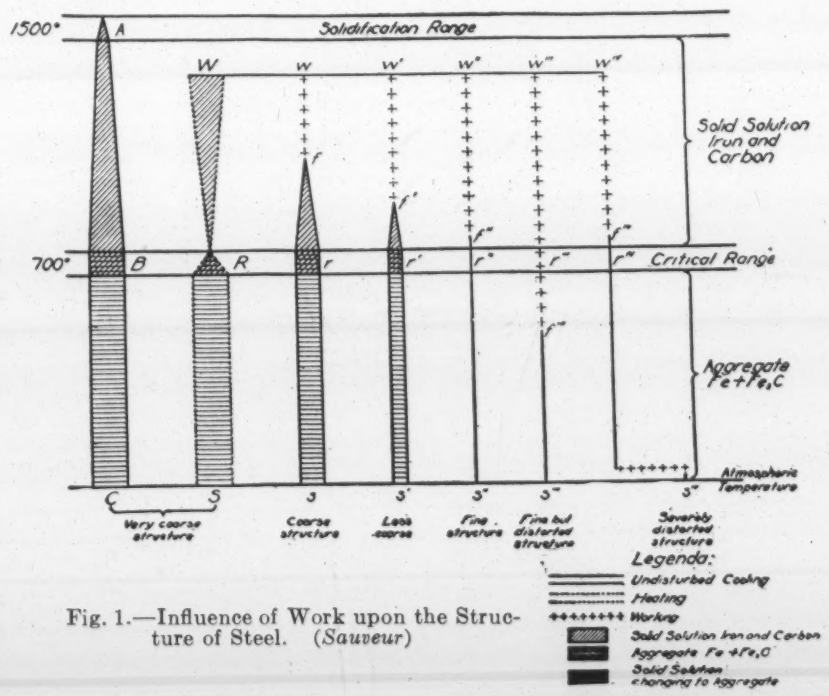



Fig. 1.—Influence of Work upon the Structure of Steel. (*Sauveur*)

Diagram *ABC* represents the solidification and cooling of a steel ingot with no working. As it solidifies at *A*, dendrites are formed and on further cooling to the critical range *B*, coarse grains form due to the slow

* The Connecticut Light and Power Company, Hartford, Connecticut.

[1] D. K. Bullens. Steel and Its Heat Treatment. John Wiley & Sons, 1927, page 480.

[2] Albert Sauveur. The Metallography and Heat Treatment of Iron and Steel. McGraw-Hill Book Co., 1926, page 168.

undisturbed cooling. In passing through the critical range, *B*, the austenite grains are converted into pearlitic grains with or without rejection of free ferrite or of free cementite, depending upon the carbon content of the steel. On cooling from the critical range to atmospheric temperature, *C*, there is no further crystal growth, but the grains have the size attained at the critical range, represented by the shaded area. If this ingot with its coarsely crystalline structure is reheated for forging, as shown in diagram *S R W*, to the temperature *W*, it is converted into a nearly amorphous solid solution after it passes through the critical range at *R*, at which point it has a very fine structure. As it is heated from *R* to *W*, the grain size grows rapidly, so that at *W*, the structure is coarsely crystalline as indicated in the diagram *S R W*.

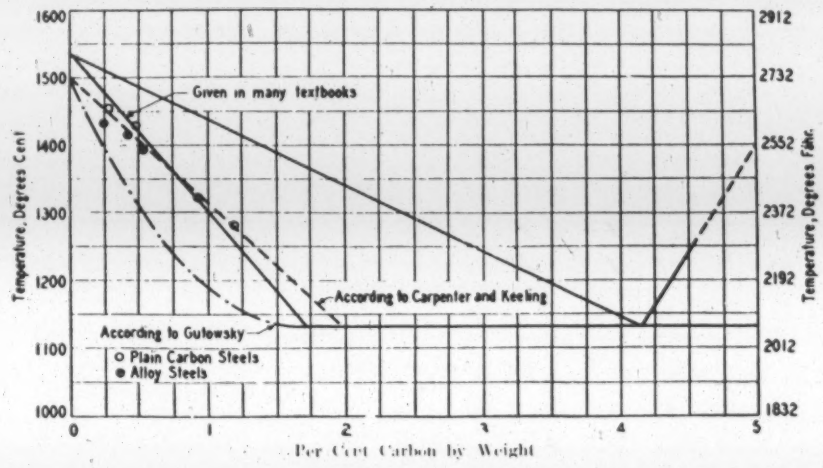



Fig. 2.—Solidus and Liquidus Lines in Iron-Carbon Diagrams. (*Jominy*)

On forging the then plastic ingot, as in diagram *w f r s*, this coarse crystallization is broken up and the formation of a new one is prevented as long as work continues vigorously, for undisturbed cooling is essential to the ready growth of crystals. However, if forging is stopped with the piece at the temperature *f*, considerably above the critical range, *r*, the steel will immediately begin to crystallize and will continue to crystallize until it has dropped to the temperature of the critical range, *r*, where grain growth stops, and the austenite grains just formed are converted into as many pearlite grains with or without rejection of free ferrite or free cementite. As the for ging cools below the critical range to atmospheric temperature *s*, it still retains the grain size at *r*, the critical range, but in this case smaller than that of the steel ingot which crystallized with undisturbed cooling, but still large with a coarse structure.

If forging of the ingot had continued to the temperature *f'*, as in diagram *w' f' r' s'*, considerably closer to the critical range than *f*, the period of undisturbed cooling with no working would have been considerably shortened, from *f'* to *r'*, and the final grain size would have been small, much smaller than when work ceased at *f*.

The effect of close adjustment of initial heating temperature, rate of forging and finishing temperature is shown in diagram *w'' f'' r'' s''*, where forging stopped at the critical range *r''*. This has resulted in a very fine grain structure, because there has been no period of undisturbed cooling above the critical range, and hence large crystals can not grow. It is also important not to continue forging much below the critical range as in diagram *w''' r''' f''' s'''*, or distortion results, because cold working not hot working is taking place below the critical range. In cold working the steel remains permanently deformed.

The necessity of the application of the fundamental principles of heating for heat treatment to heating for forging is evident with an understanding of the basic facts underlying Fig. 1. The heating phase of forging is fully as important as the mechanical phase, and both should be conducted under skilled metallurgical supervision. Metallurgical supervision should really begin with the purchase of the stock for forging. The physical properties[2] of any forging are deeply affected by the directional properties resulting from hot working, combined with dendritic segregation, which in turn is dependent upon the size and heterogeneity of the dendrites formed in solidification. The more pronounced and persistent the dendritic segregation of the ingot, the more pronounced will be the directional properties of the forging. The physical properties of a forging may vary much with the direction of testing. Steel is usually 15 to 20 percent stronger at right angles to the fiber[3] than parallel to it. Because of the occasional lots of steel which show directional properties, some gear manufacturers insist on upsetting in the forging of gears, to minimize the effect of directional properties which began with the ingot.

## THE HEATING OPERATION

With evidence of the necessity of co-ordination of initial heating temperature, rate of working and finishing temperature, the initial heating temperature becomes a controlling factor in the whole forging operation. If the initial heating temperature is too low the piece may not be completely shaped, by the time it has cooled to the critical range, and if working continues, distortion results. If the heating temperature is too high working may have been completed so far above the critical range that a coarse structure develops, and also the steel may have been "burned."

In the shop, steel is said to be "burned" if after heating it fractures when forged. Sometimes a "burned" steel does not fracture during forging, but is brittle and fails at a later time while in use, showing a fracture that is very coarse, with the fracture around the grains, not through them. As Jominy[4] states the words "burned" or "burning" are not accurately used in their application to this phenomenon, since they imply chemical reaction of steel with oxygen, whereas this reaction is not necessary to produce "burned" metal, and usually "burning" is produced by a separation of the crystals leaving voids around the crystal boundaries causing a condition of brittleness or lack of strength or both.

To establish the initial temperature of heating Hatfield[5] suggests that the liquidus and solidus of each type of steel be determined, and that the temperature of heating should not be allowed to go higher than within 180° F. (82° C.) of the solidus. Following this method Table II[5] indicates how the permissible

[3] E. F. Davis. Metallurgical Problems of Transmission Gearing. *Transactions American Society for Steel Treating*, Vol. 15, Dec. 1928, page 831.

[4] W. E. Jominy. A Study of Burning and Overheating of Steel. *Transactions American Society for Steel Treating*, Vol. 15, Aug. 1929, page 298; Sept. 1929, page 372; Dec. 1929, page 893.

[5] W. H. Hatfield. The Application of Science to the Steel Industry. *Transactions American Society for Steel Treating*, Vol. 15, May 1929, page 817.

maximum heating temperature may vary for different steels.

**Table II—Forging Temperatures**

| Material | Suggested Maximum Forging Temperatures ° C. | ° F. | Theoretical "Burning" Temperatures ° C. | ° F. |
|---|---|---|---|---|
| 1.5% Carbon steel | 1050 | 1920 | 1140 | 2080 |
| 1.1% Carbon steel | 1080 | 1980 | 1180 | 2140 |
| 0.9% Carbon steel | 1120 | 2050 | 1220 | 2230 |
| 0.7% Carbon steel | 1180 | 2140 | 1280 | 2340 |
| 0.5% Carbon steel | 1250 | 2280 | 1350 | 2460 |
| 0.2% Carbon steel | 1320 | 2410 | 1470 | 2680 |
| 0.1% Carbon steel | 1350 | 2460 | 1490 | 2710 |
| Silico manganese spring steel | 1250 | 2280 | 1350 | 2460 |
| 3% Nickel steel | 1250 | 2280 | 1370 | 2500 |
| 3% Nickel chromium steel | 1250 | 2280 | 1370 | 2500 |
| Air hardening Ni-Cr steel | 1250 | 2280 | 1370 | 2500 |
| 5% Nickel (case hardening steel) | 1270 | 2320 | 1450 | 2640 |
| Chromium vanadium steel | 1250 | 2280 | 1350 | 2460 |
| High speed steel | 1300 | 2370 | 1380 | 2520 |
| Stainless steel | 1280 | 2340 | 1380 | 2520 |
| Austenitic Cr-Ni steel | 1300 | 2370 | 1420 | 2590 |

The use of the solidus line of the iron-carbon diagram, however, seems a questionable procedure, as its position is open to considerable difference of opinion as shown in Fig. 2, on which are located three solidus lines: (1) that determined by Carpenter and Keeling; (2) that determined by Gutowsky; and (3) that given in many textbooks. The burning temperatures of commercial carbon-steels determined in the research of Jominy[4] are also plotted, and come close to the solidus line of Carpenter and Keeling. A few points are shown for alloy steels, indicating a burning point only slightly lower than for carbon steels.

With the location of the solidus line somewhat indefinite, it would seem advisable to use it as a means of determination of the initial heating temperature for heating for forging only in combination with skilled supervision and practical experience. From either of the solidus lines shown in Fig. 2, it is evident that the higher the carbon content of the steel the lower must be the temperature of initial heating if "burning" is to be avoided. Table III[4] shows the maximum temperature to which certain steels may be heated without danger of overheating or burning, provided that the furnace atmosphere is not an oxidizing turbulent one; that the heating period does not exceed two hours; and that the steel is normalized after forging.

**Table III—Forging Temperatures**

| Type of Steel S. A. E. No. | Composition of Steel Carbon % | Nickel % | Chromium % | Manganese % | Maximum Temperature at which steel may be heated if overheating and burning are to be avoided ° F. |
|---|---|---|---|---|---|
| 1015 | 0.17 | None | None | 0.58 | 2650 |
| 1030 | 0.30 | None | None | 0.65 | 2600 |
| 1050 | 0.52 | None | None | 0.64 | 2525 |
| 1090 | 0.88 | None | None | 0.34 | 2375 |
| 3145 | 0.44 | 1.20 | 0.74 | 0.64 | 2450 |

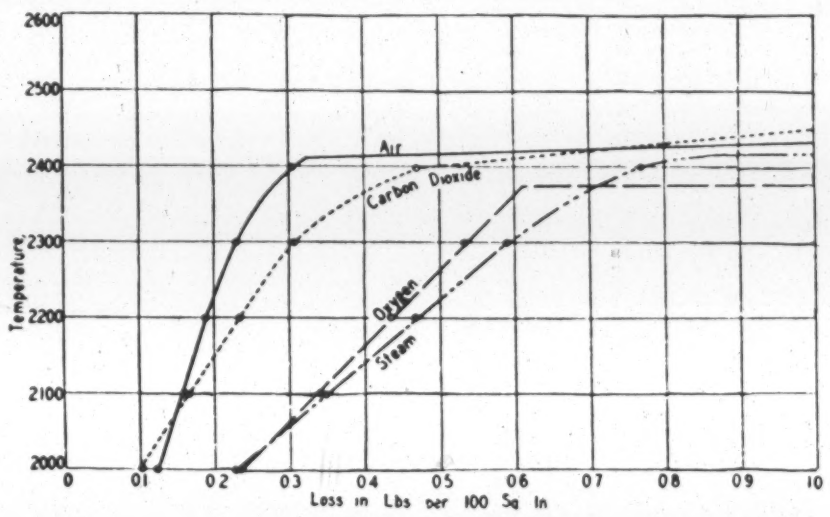



Fig. 3.—Effect of Variation of Temperature on Scaling of Steel in Several Atmospheres. (*Jominy*)

In heating for forging it is also important that the initial heating temperature be kept as low as practical, because of the increase in rate of scaling with increase in temperature. The rate of scaling increases rapidly, when the temperature exceeds 2400° F., Fig. 3,[6] which shows the effect of variation in temperature on the scaling of steel in air, carbon dioxide, oxygen and steam.

Although the effects of reducing and oxidizing atmospheres have been apparent in a general way to the forging industry for some time, little research has been performed until recently to establish facts of a definite nature. From his recent extensive research on the burning and overheating of steel, performed in a gas furnace, Jominy[4] draws the following conclusions:

(1) "A reducing atmosphere seems to protect plain carbon steels having a carbon content of 0.55% or less from burning. If the atmosphere is reducing enough to produce carburization these steels will not burn. This is not true of high carbon steels containing 0.85% carbon or more.

(2) A turbulent, strongly oxidizing atmosphere will cause these lower carbon steels to burn at relatively low furnace temperatures; a 0.47 carbon steel will burn at 2500° F. in such an atmosphere.

(3) When heated in a turbulent, strongly oxidizing atmosphere to furnace temperatures of 2500° F. or higher, plain carbon steels actually become hotter than the furnace atmosphere in which they are heated.....by reason of the exothermic reaction between iron and oxygen.

(4) The burning of steel has been found to occur in a vacuum, that is, voids between the crystals are produced, probably due to the fact that crystal boundaries melt out at these temperatures."

The rate of heating affects not only the quality of the finished forging but also the over-all cost of the forging operation. Too rapid a rate of heating may result in the working of stock apparently at temperature, but actually having a somewhat cooler interior. The difference in temperature existing between the surface of the stock and its center when the surface was heated to 2200° F. is shown for various sizes and shapes in Table IV.[7]

**Table IV—Effect of Rate Heating on Heat Penetrations at 2200° F.**

| Size of Bar | Time to Heat Surface to 2200° F. Minutes | Temperature Difference between Surface and Center, ° F |
|---|---|---|
| 1.5 in. round | 5 | 24 |
| 2 " " | 4.5 | 81 |
| 2.5 " " | 5.5 | 100 |
| 3 " " | 8.5 | 96 |
| 3 " " | 15.5 | 57 |
| 1.5 " square | 6.5 | 24 |
| 2.5 " " | 7 | 76 |
| 2.5 " " | 12.5 | 43 |
| 3.5 " " | 10.5 | 102 |
| 3.5 " " | 12 | 77 |
| 4 " " | 13.5 | 143 |
| 4 " " | 15.5 | 85 |
| 4 " " | 19.5 | 56 |

The difference in temperature between the surface and center increased with the size of the pieces and the rate of heating. In the case of the 4 in. square bars, decreasing the time of heating from 19.5 minutes to 13.5 minutes, or 6 minutes, increased the difference in temperature between the surface and center, from 56 to 143° F., or 87° F. All of the bars in Table IV seem

[6] W. E. Jominy & D W. Murphy. Scaling of Steel at Forging Temperatures. *Chicago Meeting, American Society for Steel Treating*, Sept. 1930.

[7] W. E. Jominy. The Influence of the Constitutional Characteristics of Steel on the Design of Forging Furnaces. *Atlantic City Meeting, American Gas Association*, Oct. 1929.

to have been heated at a rather fast rate. Kielman[8] states that steel for drop forging can be heated at the rate of 8 to 10 minutes (0.13 to 0.16 hours) per inch of thickness and that forging ingots or bars more than

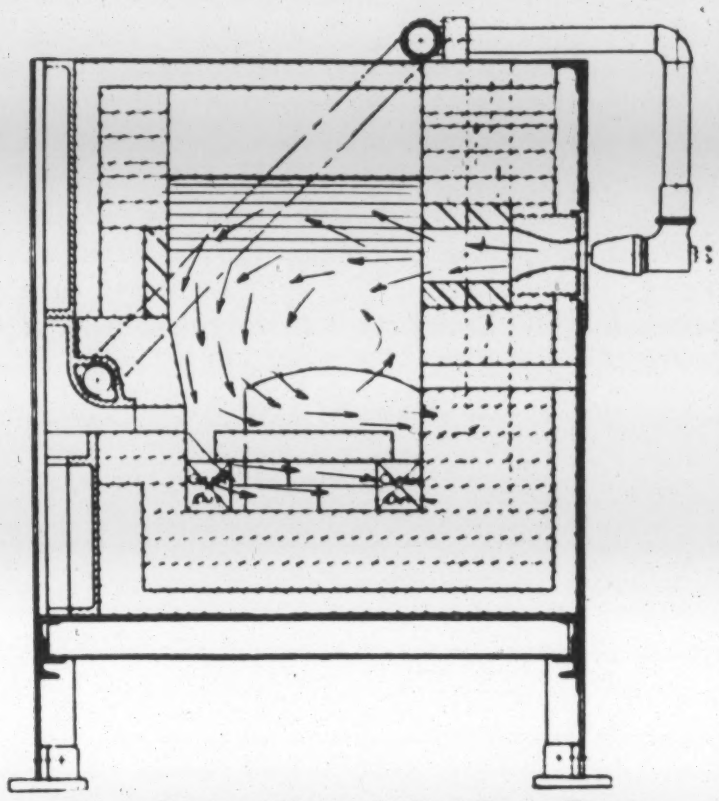


Fig. 4.—Interior of Modern Oil Fired Forging Furnace.

3 inches thick can be heated at the rate of 20 minutes (0.33 hours) per inch of thickness, if they are carbon steel, and at the rate of 30 minutes (one half hour) per inch of thickness if they are alloy steel.

The rate of heating is not only a question of heat penetration but one of scaling, for increase in time of exposure causes increase in the amount of scale produced. Scale constitutes not only an economic loss equal to the value of the steel transformed into scale, but also may affect the quality of the forging and increase its cost. If the scale is worked into the forging a weak spot results, or the forging may have a wrong dimension. Costs are increased by:

(1) High refractory maintenance expense from fusion of the furnace floor with the scale.

(2) Increased labor cost from the necessity of scraping scale from the stock before forging and from sticking of the forging in the dies.

(3) Increased machining expense.

As in heating for heat treatment, practical considerations usually require a soaking period after the surface of the stock has reached temperature, for even with a suitable rate of heating, the temperature of the interior of the stock lags behind that of the surface.

Control of the factors involved in heating for forging—initial heating temperature, atmosphere of furnace, rate of heating and time at temperature—is of such vital importance in the production of a high quality forging that it is surprising that it is so often left almost entirely to the rule of thumb operator. With management realizing the importance of controlled heating, a revolution in methods and equipment seems underway. Controlled heating results not only in an improved product, but lowers costs and increases production.

[8] John C. Kielman. Practical Points on Furnace Design. *Metal Progress*, Vol. 18, Sept. 1930, page 58.

## THE FORGING FURNACE

The production of satisfactory forging from the correct steel under skilled metallurgical supervision requires suitable heating equipment:

(1) A uniformly heated furnace chamber, designed so as to result in uniform application of heat to the stock.

(2) Temperature control equipment of such a nature as to prevent heating the stock above the desired temperature.

(3) Atmospheric control.

Thoughtful consideration of the fundamentals involved in heating for forging will indicate clearly that the day of satisfying the requirements of modern industry for uniform forgings, with the product of a pile of brick having a burner inserted at one end and operated under little or no metallurgical supervision, is past. Controlled heat is essential and controlled heat means control of all air and fuel entering the furnace with a resulting control of temperature and atmosphere. Controlled heat in forging not only tends toward an improved product, but lowers production costs, through savings in fuel, labor and maintenance of refractories.

Fig. 4 is a cross section through the interior of a modern slot type forging furnace direct fired with oil and completely equipped with automatic control, Fig. 5. The furnace is one of the types used by the Great Lakes Forge Co.,[9] Chicago, Ill. and by the Moore Drop Forging Co., Springfield, Mass. In this furnace the gases cannot short circuit out of the furnace chamber without first passing around the stock, and they leave the chamber at its floor level.

There recently has been a distinct trend toward the mechanical handling of stock to be heated for forging,

[9] A. M. Steever. Modern Drop Forging. *R-S Industrial Heat Review*, April 1930, page 4.

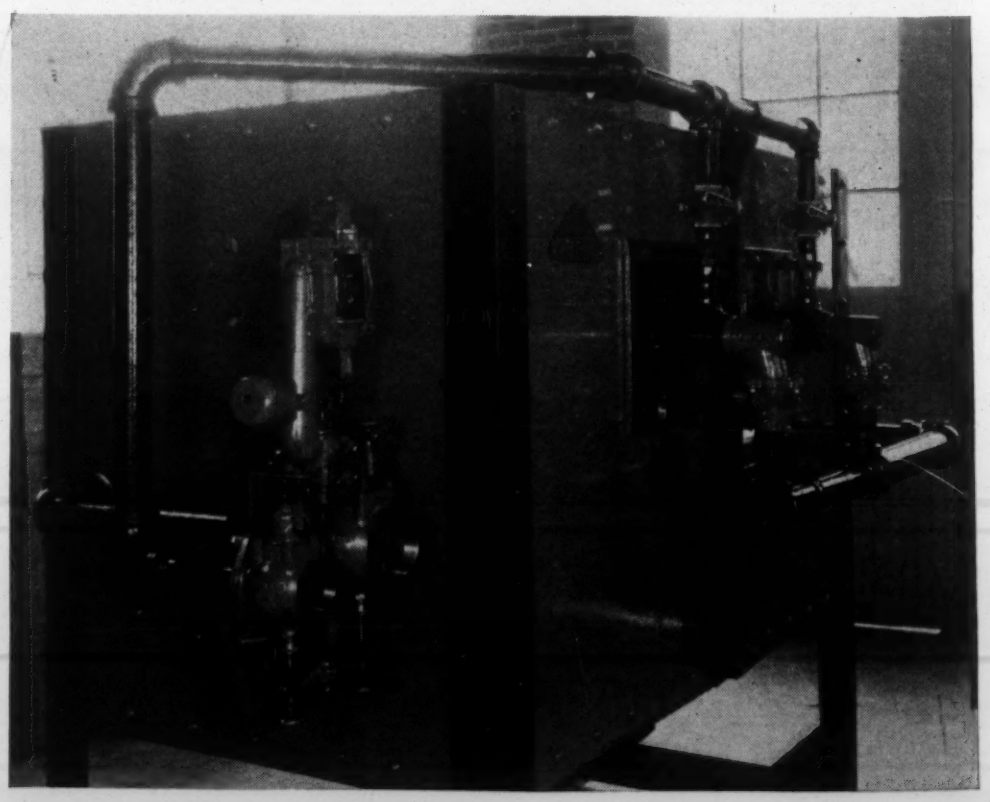


Fig. 5.—Automatic Control of Modern Oil Fired Forging Furnace. (*Ryan, Scully & Co.*)

Fig. 6, which is the charging end of a modern pusher type grooved hearth billet heating furnace heated with natural gas, and installed in the plant of the Pittsburgh Forging Co., at Coraopolis, Pa. The heating chamber is 4 ft. 6 in. wide, 21 ft. 9 in. long and $17^7/_8$ in. high. The furnace is fired by low pressure gas burners located in the side walls and discharge end wall of the furnace chamber. The products of combustion are vented through ports at the hearth level through the side walls and at the charging end of the furnace. The stock, billets $4^1/_4$ in. square by 9 in. long, are pushed end to end through the furnace in V grooves on a refractory hearth, and are discharged at the rear through a side door. The heating temperature is 2250° F., and the production 3450 lbs. per hour with a gas consumption of 1.2 cu. ft./lb. at capacity output.

Successful application of the extensive research conducted on heating for forging during recent years requires the use of suitable equipment. The furnace manufacturer through much expensive development work has raised the standard of forging furnace design to a marked degree. Competition will overcome antique equipment in the forging industry as it has in heat treating for money will talk through lower direct costs, as well as improved quality.

## THE SOURCE OF HEAT

Oil is the more prevalent source of heat for forging because its "form value" offers advantages over coal which more than offsets its higher B. t. u. cost, and any advantages which might result from the higher "form values" of gaseous fuels and electricity with their higher B. t. u. costs, are not yet apparent to the forging industry to a degree resulting in their wide spread adoption, although within recent years many gas fired forging furnaces have been installed. In heating for forging, gaseous fuels and electricity can seriously compete with oil only on a basis of "heat cost," that is B. t. u. cost and efficiency of utilization, except in special applications. Extensive research[4] indicates

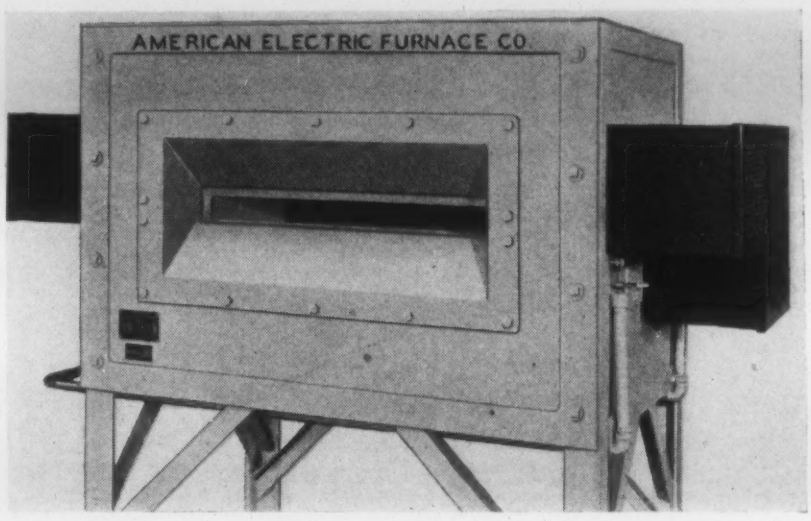



Fig. 7.—40 Kw. Electric Forging Furnace Having Globar Resistors. (*American Electric Furnace Co.*)

the possibility of closer control of heat and atmosphere with gas than prevails in many of the present oil fired forging furnaces. Offsetting this is the luminous flame of oil which radiates heat about four times as rapidly as a non-luminous flame and heats the stock more rapidly, and also the fact that little research has been done on the possibility of accurate control of atmosphere in a forging furnace heated with oil.

Although the first industrial electric furnace for heating for heat treatment was a forging furnace of the granular carbon resistor type exhibited by Baily at Pittsburgh in 1913, electricity has not been applied to any extent as a source of heat for forging. A large automobile manufacturer has an extensive installation,[10] of 55 units of two sizes, 337 kw. and 540 kw., presumably made because the electric furnace fitted well into the line of production with improved working conditions. Fig. 7 shows a 40 kw. slot type electric forging furnace 28 in. long, $2^1/_2$ in. high by 8 in. deep having silicon carbide resistors. The use of electricity for heating for forging tends to increase, but its progress for this heating application is very slow compared with that of gas, possibly because through improved methods of manufacture and through the extension of natural gas lines, gas is becoming more closely competitive with oil on the basis of "heat cost." The fundamental principles involved in the selection of the source of heat for heat treatment apply to forging, but in the present knowledge of the art, "heat cost," carries greater weight than "form value," a situation which may or may not be changed by research.

In forging, heating is at least equal in importance to mechanical working, but more important than either is coördination of both under skilled metallurgical supervision, if a forging of high quality is to be produced.

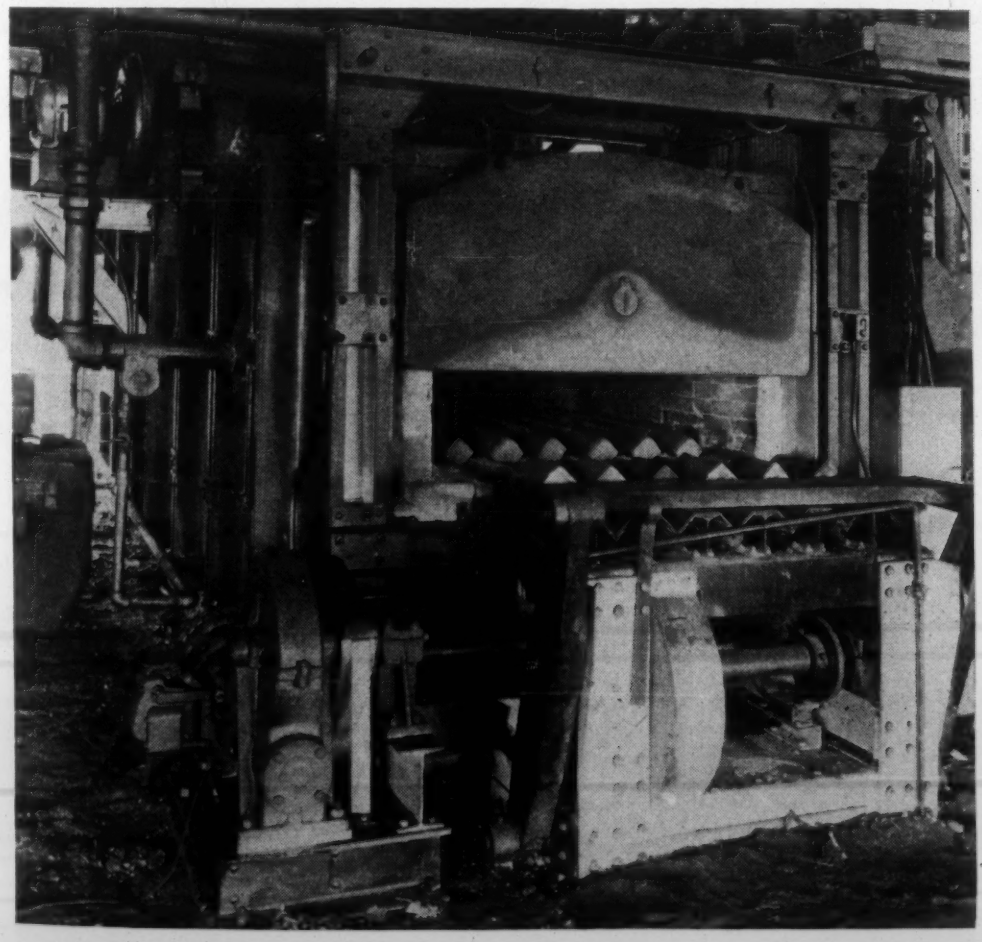


Fig. 6.—Pusher Type Billet Heating Furnace Fired with Natural Gas, Pittsburgh Forging Co., Coraopolis, Pa. (*Electric Furnace Co.*)

[10] Ford Forges with Electric Heat. *Electrical World*, Vol. 96, Nov. 15, 1930, page 902.

(*Continued from page 2*)

Regarding the value of our patent office, practical inventive genius is a special ability just as much as unusual executive ability. The executive wants returns. So does the practical inventor. Corporations are getting only such returns to-day as might be expected from treating men of special ability simply as technical mechanics, and such as would result from giving chief executives the consideration usually handed to straw bosses.

And the type of mind behind this situation is about as likely to be improved as is the patent situation. It will require a new era with new ideals concerning the creative mind.

ROBERTSON MATTHEWS.

Research and Development Engineer
Detroit, Mich.
Oct. 21, 1930.

## Space Lattice of Cementite

To the Editor of METALS & ALLOYS:

Re—Space Lattice of Cementite.

According to Honda (*Metal Progress*, November 1930, page 87) Shimura has determined the location of the individual atoms in the cementite unit cell. If the proposed arrangement is correctly understood by the writer, it involves pairs of one carbon and one iron atom whose distance apart, according to the parameters given is

$$\sqrt{[(0.415 - 0.1987)5.04]^2 + [(0.205 - 0.181)4.51]^2}$$

or 1.09+ A. U.

Now the radius of the carbon atom is probably about 0.75 A. U. and of the iron atom 1.24 A. U. (see for example, Jeffries and Archer, "Science of Metals," page 5) which gives for the minimum distance of a carbon and iron atom 1.99 A. U. unless great atomic deformation is possible.

Since the configuration of neither the iron nor the carbon atom suggests the plausibility of such distortion, the need of assuming that the center of a carbon atom approaches that of an iron atom more closely than the outer electrons of the latter usually approach the nucleus, would seem to cast serious doubt upon Shimura's conclusions.

The writer has neither the data nor the interpretive skill to determine whether Shimura's observations are reconcilable with a shift of the entire system of carbon atoms which would maintain their relative positions and place each where there is room for it between the present locii of iron atoms.

A preliminary calculation seems to indicate that such vacancies could be found.

H. A. SCHWARTZ.

Director of Research,
National Malleable & Steel Castings Co.
Dec. 4, 1930.

## CORRECTION

Editor, METALS & ALLOYS:

An error was made at the end of my article on "Cupola Melting of Bronze," page 813 of the November issue. The price paid for Barrett pitch coke has been $35.00 a ton, not $33.00.

However, the price fell to $25.00 on December 1st, 1930, thus reducing the present fuel cost to 8c per 100 lbs. of metal melted.

E. R. DARBY.

Federal-Mogul Corp.,
November 28, 1930.

◆ ◆ ◆

## Chuckles

A new theory on fatigue of metals has been propounded in the advertising literature of a certain pig iron which "has certain characteristics and qualities . . . that cannot be found through chemical analysis in the ordinary laboratory. . . . A casting is made according to certain specifications and analysis. It is then put into use, subjected to the shock and strain that its duty imposes on it, and later on it breaks. . . . If the broken casting contains the same chemical analysis, and has not lost any appreciable weight, is properly designed and made, what causes it to break after performing its duty properly for a given length of time?

"According to one of the electronic theories the casting or metal has become fatigued, caused by the electrons going off into space during the performance of its duty. If this be so, it is plainly seen why the continued use of scrap over and over is bound to result in inferior castings. Inasmuch as the quality of scrap is such an unknown factor, it becomes more and more essential for the steel maker and foundryman to select the highest grade of pig iron obtainable for the base of his mixture. . . . It is our contention that the ore (from which . . . pig iron is made) contains either more, or an exceptional combination of electrons, or both, than any other known ore, and that these exceptional features carry on into the iron through the process of refinement."

Now we know at last how to devise an accelerated endurance test! Let the physicist rig up a Geiger counter to show how fast the electrons fly off while the metal specimen is performing its duty.

Unfortunately this will still require a little proof, for the salesman for this pig iron said he wasn't *absolutely* sure it was the electrons that were so much better in his ore; it might be some other God-given property. Some one is always taking the joy out of life in connection with accelerated fatigue tests.

## A Big Noise

Stenographic Report—12th Semi-Annual Meeting, Open-Hearth Committee, A. I. M. M. E.

Hotel Cleveland, Cleveland, Ohio, Friday Morning, Nov. 21, 1930

Topic—Benefits derived from the use of "Densite"

Chairman L. F. Reinartz (American Rolling Mill Co.)—"The next subject is the use of 'Densite.' I understand that Mr. Ramsey has used some of this deoxidizer."

Mr. E. I. Ramsey (Wisconsin Steel Co.)—"While it was reported that we used 'Densite,' that is a false alarm. We never used it. We said that if any of our customers wanted 'Densite'-treated steel, we might try it, but we haven't had a call for it yet, and I hope we do not."

Chairman—"Dr. Herty, have you heard anything about this material?"

Dr. C. H. Herty, Jr. (U. S. Bureau of Mines)—"We were asked to follow a heat that was to be 'Densite'-treated, in order to get a comparison between it and one made in the usual way. The way we did it was on an acid furnace. We poured a 25-lb. ingot out of the furnace just before the heat was tapped, and it was dead.

"The 'Densite' was thrown into the ladle. In between the first and second big ingot we poured another 25-lb. ingot on the pouring platform. This gave us two small ingots with and without 'Densite.' We have the following report. (Reads from report)—The following are the results from the 'Densite'-treated heat. It looks like an expensive pyrotechnic display.

| | Untreated | 'Densite'-treated |
|---|---|---|
| Elastic limit lbs./in.$^2$ | 84,000 | 83,000 |
| Ultimate strength lbs./in.$^2$ | 184,500 | 177,500 |
| Elongation % | 13 | 13 |
| Reduction of area % | 25 | 26½ |

"The small ingots were forged to 1 inch square, normalized, quenched and drawn.

"We took tests out of these two ingots, and got the whole gang around, to get the pros and cons on 'Densite,' and tried to get them to spot which was which. Half of them guessed one was 'Densite'-treated, and the rest guessed the other. We figured that in the last analysis, the phrase in the report 'Looks like an expensive pyrotechnic display,' was about right."

Chairman—"How about the detonator? Did you try it on a big heat?"

An Open Hearth Superintendent—"It didn't show up anything."

Chairman—"Did it make any noise?"

Open Hearth Superintendent—"You're damn right it did. Some of the cans exploded in my hand."

# A FURNACE for Metallographic Examination of Specimens at High Temperatures

By B. A. Rogers*

THIS paper presents further results obtained with a furnace designed to permit the examination of metallographic specimens at elevated temperatures. The practice of heating objects which are under microscopic observation has been found useful in mineralogical examinations for many years, but the adaptation of the method to metallographic work has received little attention although a number of people[1,2] have considered this possibility. The principal value of such a device as used by the author has been in furnishing a check method of determining the temperature and existence of certain allotropic transformations in pure metals and alloys, and in observing the effect of such changes on the appearance of the specimens. For example, the change in the microstructure of iron at the $A_3$ transformation was discussed in a previous paper.[3] It is very probable, however, that additional uses will be found in the more theoretical investigations.

*Description of New Furnace.* Some of the results presented here were obtained with the equipment previously described, but the greater part of the work was done on the new apparatus pictured in Fig. 1. The furnace itself differs little from the earlier one. It is slightly smaller and is supported entirely by the two arms A and A′ of which one is the hydrogen inlet, and the other, the water outlet from the cooling jacket. Molybdenum wire wound on a zirconia cylinder constitutes the heating element. The surrounding refractory is magnesia. Two metal shields for covering the heating element and the water cooled cover for the furnace are to be seen lying on the base.

The essential improvement in the new model lies in the design of the mounting which is intended to permit ready leveling of the specimen and to afford a convenient means of changing the field of view. Leveling is accomplished by rotation about two horizontal axes at right angles to each other and lying approximately in the plane of the specimen as mounted for observation. One axis is provided by the tubes A and A′ and the amount of rotation about this line is controlled by the screws B and B′ which bear upon small brackets attached to the furnace wall. The other at right angles to this is furnished by the mounting shaft C which supports the entire furnace with its adjusting mechanism. The shaft is free to rotate in the bracket E, but its position is fixed by the screws D and D′ (D′ is hidden by E) which bear upon an arm attached to it. The mechanism for changing the field of view is essentially the same as that of the rotating stage of a microscope. Ring F, carrying the furnace, may be moved in its own plane within the limits set by ring G, that is, a distance of about 3 mm. along any diameter, by means of the screws H and H′. It may also be rotated about a vertical axis as far as permitted by the various connections to the furnace. The small wheel K is connected to a rack and pinion arrangement by means of which the furnace may be lowered for changing samples. This adjustment is also convenient in focusing, especially when it is undesirable to change the position of the illuminator with respect to the rest of the optical system.

Unfortunately, the quality of hydrogen used in these experiments was not as good as that formerly obtained. It was, therefore, necessary to resort to a simple train for removing the oxygen. The gas was first led through a small tube furnace maintained at red heat, then through a tube containing calcium chloride, and finally through a bubbling bottle partly filled with sulphuric acid. As a rather definite rate of flow was found essential for satisfactory results, the bubbling of the acid served as a crude gas meter. Purification of the hydrogen was not required for samples of iron unless they were to be photographed after removal from the furnace, as the oxide which formed at a low temperature usually cleared away about 500° C. and did not reappear on cooling until the temperature was somewhat lower than this. Thus, no interference was experienced in the vicinity of 900° C. regardless of conditions at lower temperatures. The purification train was, however, used in practically all work.

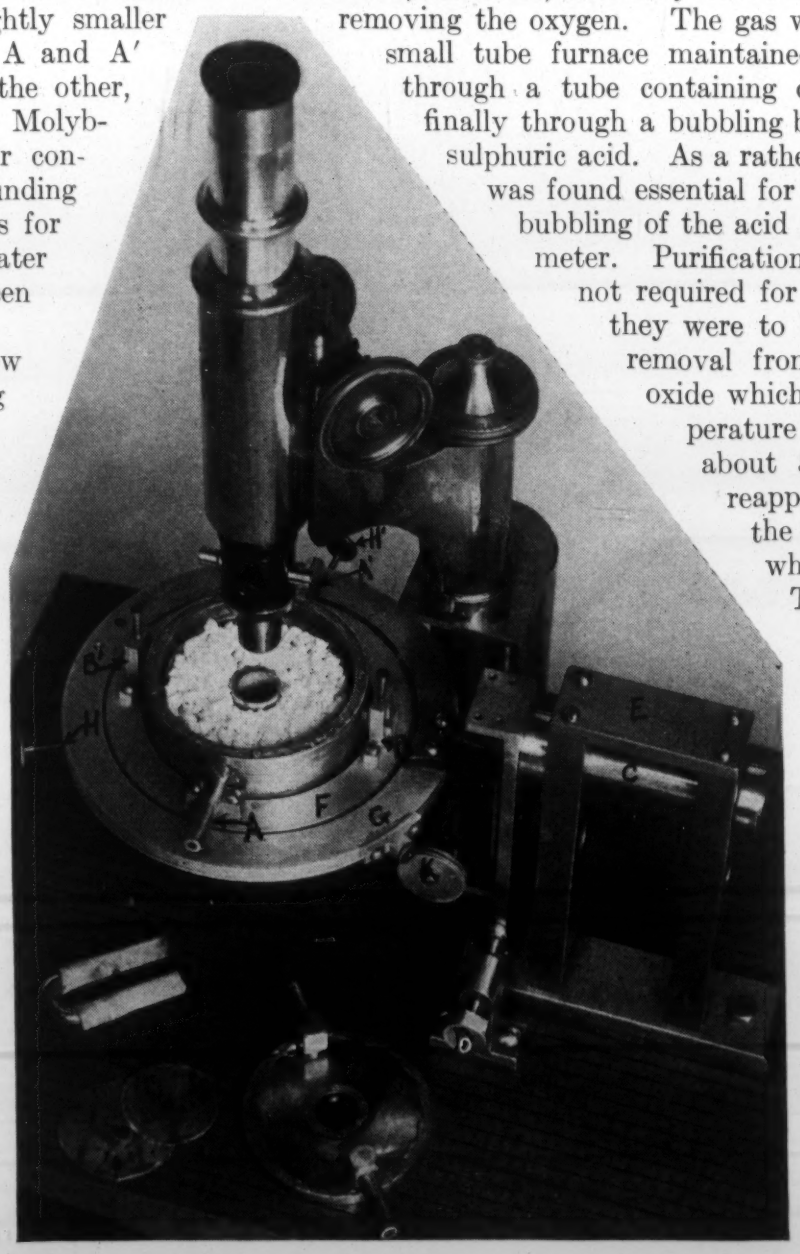



Fig. 1

## TRANSFORMATION IN PURE METALS

As has already been stated, the principal use of the furnace thus far has been to observe the changes in the surface of metallo-

* Cambridge, Mass.

[1] N. A. Ziegler. *Transactions, Iron & Steel Division, American Institute Mining & Metallurgical Engineers* (1929) page 380.

[2] J. A. Ewing & W. Rosenhain. The Crystalline Structure of Metals. *Philosophical Transactions, Royal Society*, Vol. 195A (1900) pages 279–301.

[3] Change in Microstructure of Iron at the $A_3$ Transformation Point. *Technical Publication* No. 218, *American Institute Mining & Metallurgical Engineers.*

Table 1. Data for Practically Pure Metals

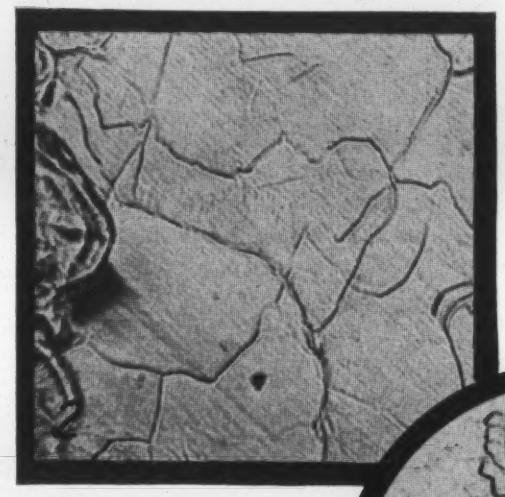
| Element | Description of Material | Max. Temp. of Sample, ° C. | Temp. of Trans.,[1] ° C. | Remarks |
|---|---|---|---|---|
| Chromium | Dense cath. plate | 900 | None | Oxidized at 700° C. |
| Cobalt | Dense cath. plate | 500 | 420 | |
| | Vacuum melted (purchased) | 1100 | 445 | Grain boundaries at 700° C. |
| Iron | Vacuum melted (electrolytic) | Melted | 911 | Grain boundaries at 500° C. |
| | | | 1400 | |
| Manganese | Distilled and vacuum melted | 900 | 742[2] | Surface shattered by transformation |
| Molybdenum | Piece of wire bar | 1200 | None | No change in appearance |
| Silicon | Purified (Ref. 6) vacuum melted | Melted | None | No change in appearance |

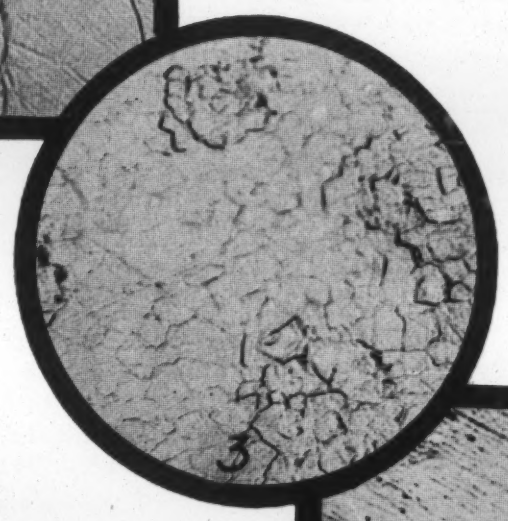
[1] Values given are for rising temperatures.
[2] Estimated only.

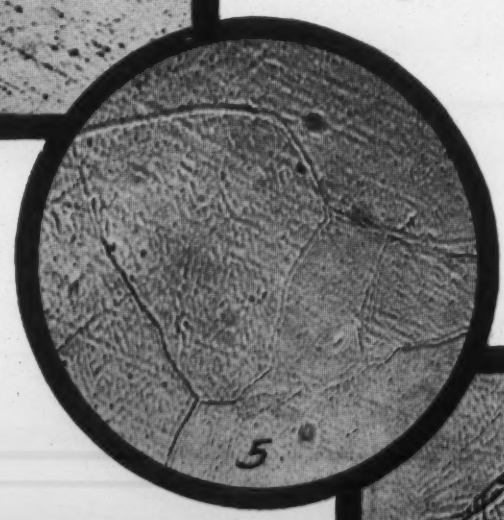
graphic specimens as they passed through transformations. Six metals which could be considered to be of high purity have been studied and three of these showed surface changes indicative of a considerable disturbance proceeding within the body of the sample. Table 1 summarizes the results briefly.

*The Transformations in Iron.* Beginning with iron, the three metals which did show visible evidence of transformation will be discussed in detail. Iron is of particular interest because of the abruptness and vividness of the surface changes and also because it exhibits two transformations. All except one of the photomicrographs which accompany this paper are of samples of iron.

The appearance of a piece of polished iron which has been heated in a hydrogen atmosphere or in vacuo has already been the subject of a number of discussions and will be considered here only in connection with the structural changes brought about by passing through a visible allotropic transformation. Fig. 2 shows a field which displays both transformed and untransformed areas. This picture illustrates a case in which the transformation is seen as an eruptive wave which appears at one side of the field of view and sweeps across it. The time of passage of such a wave may be a small fraction of a second or it may be several seconds or even minutes, depending upon the rate of heating. The sample in this case was from a forged blank of electrolytic iron which had been melted in vacuo. In other cases, the transformation has begun simultaneously in a number of spots and from these origins gradually covered the field of view. Such a case is to be seen in Fig. 3 which shows the change from $\alpha$ to $\gamma$ iron in progress on a piece of iron stripped from a cathode. Both types of transformations will appear on either kind of iron although the second may be seen more frequently on the unmelted variety. It is probable that the rate of heating and the position of the specimen with respect to the axis of the heating element also affect the nature of the wave, but no definite relation was noticed. The samples in these figures and also in Fig. 4 were removed from the furnace before being photographed, the power having been turned off when the desired stage was reached.







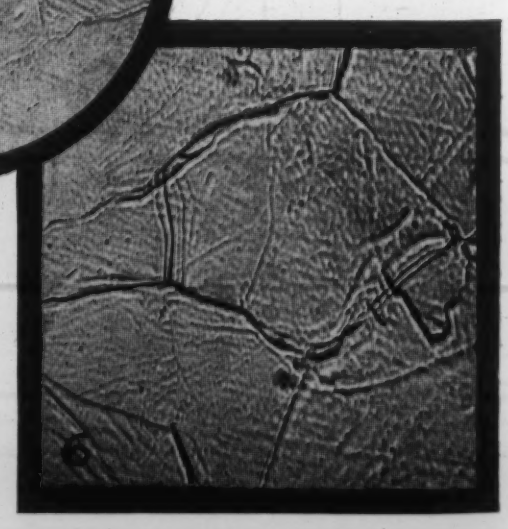


Fig. 2. —Magnification 51×
Fig. 3. —Magnification 80×
Fig. 4. —Magnification 100×
Fig. 5. —Temperature 890° C. Magnification 160×
Fig. 6. —Temperature 920° C. Magnification 160×

In a number of cases a rather abrupt widening of the grain boundaries on specimens has been noted just before the appearance of the wave. Fig. 4 displays a rather unusual variation of this effect on a piece of cast material. Until the temperature reached 900° C., there was a simple coarse grain boundary extending across the field shown. When the transformation wave had approached to a point about one or two hundredths of an inch (on the specimen) above the area shown, the group of small grains burst into existence. As a comment upon the specimen itself, it may be said that the lower part of the grain boundary shown indicated considerable evidence of foreign material. It should also be stated that it was not originally intended to photograph this sample and it was, therefore, polished only roughly as the photomicrograph shows.

*Photomicrographs of Heated Samples.* The next five photomicrographs were taken with the samples actually in the micro-furnace and at the temperatures indicated. A 16 mm. objective, a 20× eyepiece, and a tube length of 165 mm. plus the length of the illuminator were used. The camera was a remodeled film-pack instrument with the lens removed and the plate holder was simply laid on top and held in position by the hand. A rough measurement indicated that the distance from the eyepiece to the photographic plate was 23 cm. Approximate duplication of these conditions on an ordinary metallographic camera showed that the magnification was about 160 diameters. In using the 16 mm. objective, it was necessary to place the specimen very near the top of the heating element and quite close to the window and to lower the objective to a millimeter or less from the top of the window, yet no trouble due to heating of the lens was experienced. Even after 10 minutes in the position required for photography, the

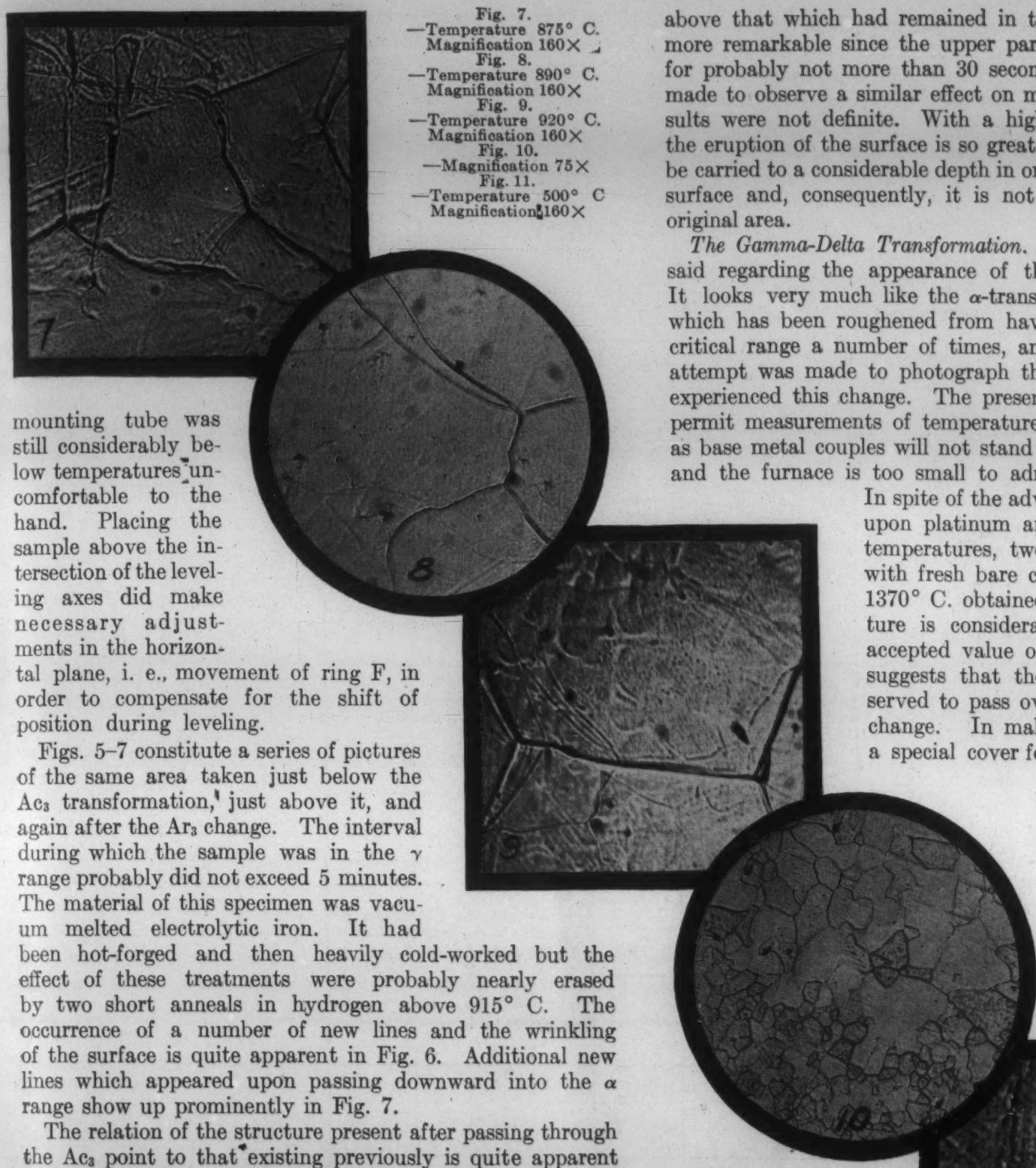


Fig. 7. —Temperature 875° C. Magnification 160×
Fig. 8. —Temperature 890° C. Magnification 160×
Fig. 9. —Temperature 920° C. Magnification 160×
Fig. 10. —Magnification 75×
Fig. 11. —Temperature 500° C Magnification 160×

mounting tube was still considerably below temperatures uncomfortable to the hand. Placing the sample above the intersection of the leveling axes did make necessary adjustments in the horizontal plane, i. e., movement of ring F, in order to compensate for the shift of position during leveling.

Figs. 5–7 constitute a series of pictures of the same area taken just below the $Ac_3$ transformation, just above it, and again after the $Ar_3$ change. The interval during which the sample was in the $\gamma$ range probably did not exceed 5 minutes. The material of this specimen was vacuum melted electrolytic iron. It had been hot-forged and then heavily cold-worked but the effect of these treatments were probably nearly erased by two short anneals in hydrogen above 915° C. The occurrence of a number of new lines and the wrinkling of the surface is quite apparent in Fig. 6. Additional new lines which appeared upon passing downward into the $\alpha$ range show up prominently in Fig. 7.

The relation of the structure present after passing through the $Ac_3$ point to that existing previously is quite apparent in the above series. However, this relationship is very little in evidence in the next pair of photographs, Figs. 8 and 9. To be sure, the original structure can be traced in Fig. 9 but the new network bears no apparent relation to it. The subject of these photographs was cut from the same piece as the specimen of the previous series but did not receive the two anneals in hydrogen. Whether the omission of the annealings is of any significance in the relations between the networks, the author is not prepared to say.

Before leaving the discussion of the $A_3$ transformation, it seems appropriate to make the comment that with the best material which was available, i. e., about 0.05 total impurities of which half was copper, and with oxygen nil by the vacuum fusion method, the eruption of the surface upon transformation has appeared quite as disturbing if not more so than in the case of samples which were less nearly pure. In this class of material, the experiments with the microfurnace do not point toward a disappearance of the space lattice transformations in very pure iron as postulated by Yensen.[4]

*Grain Growth in Cathode Iron.* Fig. 10 shows a piece of cathode iron which had been carried part of the way through the transformation and then repolished. The increase in grain size of the upper region which had been transformed above that which had remained in the $\alpha$ condition is the more remarkable since the upper part had been austenitic for probably not more than 30 seconds. An attempt was made to observe a similar effect on melted iron but the results were not definite. With a high purity melted iron, the eruption of the surface is so great that repolishing must be carried to a considerable depth in order to get a new plane surface and, consequently, it is not easy to identify the original area.

*The Gamma-Delta Transformation.* There is little to be said regarding the appearance of the $\gamma$-$\delta$-transformation. It looks very much like the $\alpha$-transformation on a sample which has been roughened from having been through the critical range a number of times, and, for this reason, no attempt was made to photograph the sample after it had experienced this change. The present equipment does not permit measurements of temperature as high as 1400° C., as base metal couples will not stand so high a temperature and the furnace is too small to admit a protecting tube. In spite of the adverse effect of hydrogen upon platinum and its alloys at such temperatures, two attempts were made with fresh bare couples and a value of 1370° C. obtained. While this temperature is considerably different from the accepted value of 1400° C., it certainly suggests that the wave which was observed to pass over was due to the $\gamma$-$\delta$ change. In making these observations a special cover for the furnace was used. It had a 1/4″ center hole and was very well cooled in the vicinity of this opening. The quartz plate was cemented on top so that the water cooled area came between the cement and the heat of the furnace.

*The Transformations in Cobalt and Manganese.* The transformation which occurs in cobalt at about 450° C. is much less abrupt than the changes that occur in pure iron. There is, instead, a comparatively gradual rise to prominence, extending over several degrees, of a set of geometric figures which show up because they lie in low relief and are, in fact, more evident when the specimen is slightly out of focus. The prominence of these figures diminishes markedly after cooling to room temperature. Fig. 11 shows a number of designs which developed on a piece of cast cobalt. The lower temperature at which these figures appear on the electrolytic cobalt is rather puzzling, but may be due to contamination with iron.

Manganese displays a rather abrupt change in appearance upon passing through one of its lower critical points. The samples as polished show grains well separated from each other and upon heating, these grains are broken up into

[4] T. D. Yensen. Pure Iron and Allotropic Transformations. *Transactions, Iron & Steel Division, American Institute of Mining & Metallurgical Engineers* (1929) pages 330–332.

smaller fragments. The samples were much too brittle to be drilled for the insertion of a thermocouple, but the change appeared to correspond to the transformation stated by Gayler[5] as coming at 742 ± 3° C. The sample underwent considerable discoloration below this temperature, and although the coating was not thick enough to hide the surface change it did spoil the appearance for photographic purposes.

*Results on Chromium, Silicon and Molybdenum.* These elements exhibited no transformations. Neither silicon nor molybdenum displayed grain boundaries or other markings when carried to about 1300° C. except that the sample of silicon melted. Chromium developed a sketchy network which appeared to be grain boundaries, but a heavy coating, probably oxide, which developed about 800° C. prevented further observation. Molybdenum and chromium are sufficiently described in Table 1, but it should be added that the silicon was purified according to the method outlined by Tucker[6] and then remelted in vacuo.

**Table 2 Effect of Added Elements on Temperature of Transformation**

| Element | % Added | Temp. of Trans. Heating ° C. | Temp. of Trans. Cooling ° C. | Remarks |
|---|---|---|---|---|
| Silicon | 0.17 | 923 | 902 | Transformation abrupt |
| Silicon | 0.39 | 937 | 915 | Transformation very distinct but less abrupt |
| Silicon | 0.83 | 975 | ... | Transformation barely perceptible on heating |
| Molybdenum | 1.08 | 974 | 923 | Transformation abrupt |
| Manganese | 0.50 | 896 | 859 | Transformation abrupt |
| Chromium[1] | 5.38 | 845 | 815 | Transformation abrupt |

[1] From ingot, other samples from forgings.

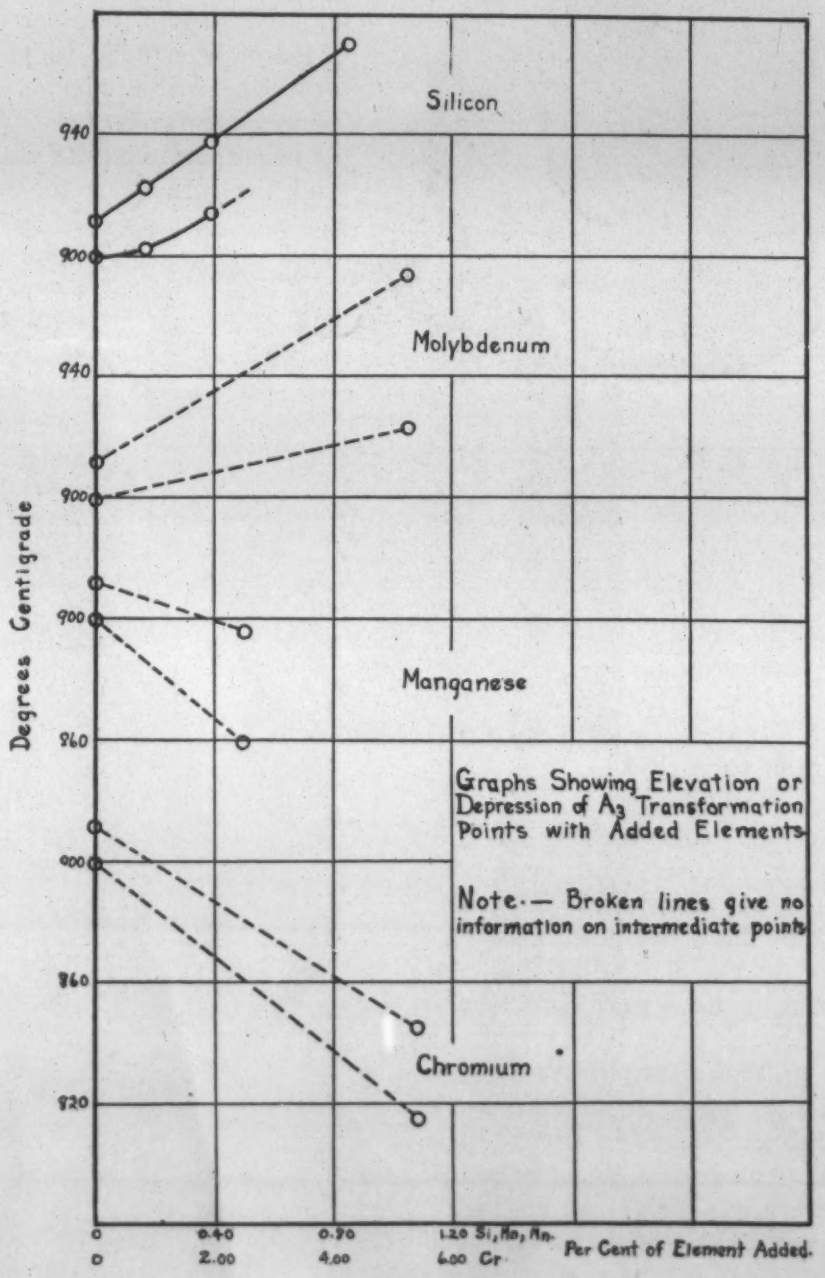



Fig. 12

## TRANSFORMATIONS IN ALLOYS OF IRON

A few experiments were made to determine whether the $\alpha$-$\gamma$ change could generally be observed in iron alloys. Curiosity in this matter was aroused by the fact that a piece of structural steel containing probably 0.1% carbon showed no abrupt change although a difference in the appearance of the sample could be observed after the austenitic state had been attained, and, on the other hand, a piece of iron-cobalt alloy containing about 50% of each element exhibited a very sudden eruption.

With the intention of investigating this matter further, four different elements were alloyed with iron. All melts were made in vacuo starting with electrolytic iron and the materials as described in Table 1. The quantitative results are to be found in Table 2 and are also shown graphically in Fig. 12. The alloys with chromium, manganese and molybdenum all gave very distinct eruptions of much the same type as that of pure iron. Perhaps in some cases, a little longer was required for the transformation to sweep across the field of view than would have been necessary for iron under the same conditions and the arrest seemed to last over a short range of temperature, but the disturbance of the surface was very similar. On samples containing 0.39% silicon the change was somewhat less distinct, and on those with 0.85% it was just perceptible. For the 0.85% alloy, the transformation could be observed only on the first passage through the critical temperature. On this alloy there appeared a peculiar checking effect just below 900° C., and a slight discoloration as if the sample were oxidizing shortly above this point. The chromium samples oxidized badly beginning about 750° C.

[5] Marie L. V. Gayler. Preparation of Pure Manganese. *Journal Iron & Steel Institute*, Vol. CXV (1927) pages 393–411.

[6] N. P. Tucker. Preparation of High Purity Silicon. *Journal Iron & Steel Institute*, Vol CXV (1927) pages 412–416.

## SUMMARY

Experiments with the furnace have shown that it is possible to observe marked surface changes upon some elements as these pass through certain allotropic transformations presumably connected with a shift of space lattice. These transformations can be traced, in iron at least, when considerable percentages of other metals have been added.

Observations at a magnification of 50 to 75 diameters can be conducted on samples heated above 1500° C. and at higher magnifications when the temperature does not exceed 1000° C. Photographs, of which several have been included with this paper, can be taken at magnifications of about 150 diameters for temperatures up to 1000° C. and presumably at lower magnifications for higher temperatures.

For their assistance in carrying out this work, I am in debted to Dr. M. Baeyertz and to Messrs. A. L. Kirby and C. C. Patton.

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## Two New Research Projects

Battelle Memorial Institute at Columbus, Ohio, announces the establishment at the Institute of two new research projects, one sponsored by the Ohio Steel Foundry Company, Springfield, Ohio, and the other by the Ironsides Company, Columbus, Ohio.

The former project will consist of a comprehensive study of steel foundry practice with a view to developing improvements and economies in practice as well as the betterment of finished products. Dr. C. H. Lorig, a member of the Institute staff and a specialist in foundry practice, will be in immediate charge of this work under the direction of Mr. Clyde E. Williams, Assistant Director.

The other project will consist of a fundamental study of lubrication in respect to metal drawing and its proper application to modern practices. Dr. Robert C. Williams, a specialist in colloidal chemistry with wide experience in this field, who joined the Institute staff on January 1, 1931, will be in charge of this program of research work under the direction of Dr. H. W Russell, chief physicist of the Institute.

Fig. 1.

By Richard Rimbach*

MORE than twenty-five years ago the New Jersey Zinc Company organized a separate department called the Technical Department, whose responsibility it is to keep the company in the forefront of scientific progress in the various phases of its metallurgical operations and to work toward expanding the uses of the company's products. One division of the Technical Department, the Research Division, is engaged in the experimental work necessary to accomplish these aims.

The Research Division, because of the New Jersey Zinc Company's extensive interests in the field of pigments devotes a considerable part of its facilities and personnel to the study of pigment problems. This article, however, will be confined to a description of the sections of the Research Division which are engaged in work on metals since it is this phase which is undoubtedly of major interest to readers of METALS & ALLOYS.

The work of the Research Division is centered at Palmerton, Penna., where the New Jersey Zinc Company has its largest metallurgical plants. The nucleus of the Division occupies about two-thirds of the Central Laboratory building in which is also housed the Testing Department's central plant control laboratory. The work in this building is of a strictly laboratory character and is, of course, only one phase of the research activities. Adjacent to one of the Palmerton plants is located the Research Field Station where a group of buildings adapted to larger scale experiments and semi-commercial scale operations has railroad facilities and is supplied with industrial power, steam and other services.

While it is slightly outside the scope of the present article, a view of the interior of one of the experimental buildings where metallurgical processes for the production of metallic zinc are studied is included. Also to illustrate the fields of research into which investigations must be pursued, a view of the laboratory devoted to a study of refractory materials vital to these metallurgical operations is also shown.

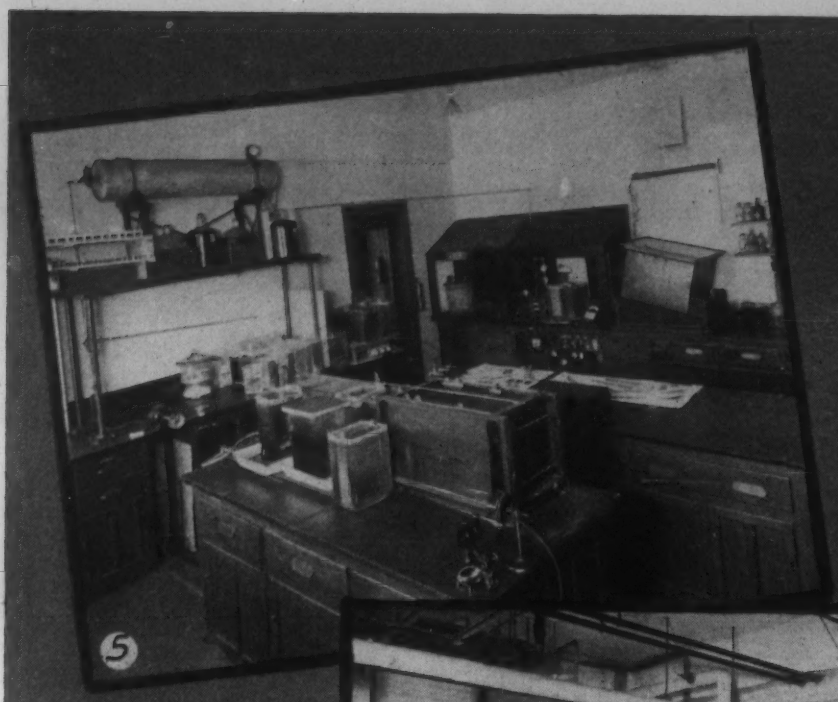
The value of any metal depends usually upon the small amounts of other elements present in it. Harmful impurities must be excluded but equally important is the knowledge of what alloying metals to add. Most commercial metals are natural or artificial alloys and the work of the sections of the Research Division dealing with the utilization of metallic zinc is centered largely about the subject of zinc alloys.

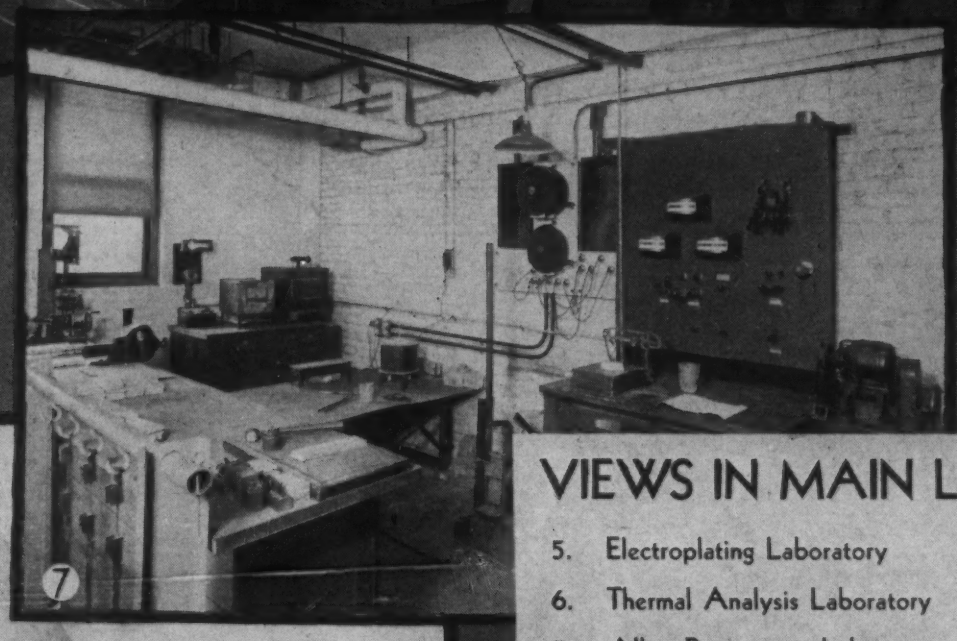
Alloy investigations involve the preparation of hundreds of compositions and for reasons of economy, the first study of any particular composition is made on a small scale but with conditions under the precise control which is possible with modern electric furnaces and control instruments. A laboratory adequately provided with such equipment is devoted to this first step in alloy study.

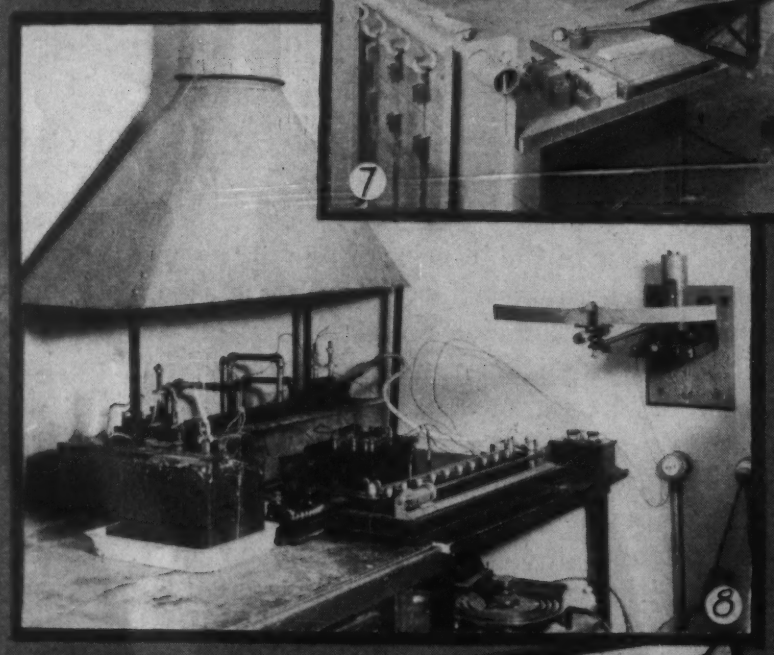
Probably the most important single tool of the metallographer is the microscope and a laboratory equipped to meet all of the needs of the metallographic microscopist is located near the alloy preparation room.

A second important means of learning about the make-up of alloys is thermal analysis or the study of cooling curves. This work requires highly specialized furnaces and temperature measuring apparatus of the highest accuracy. Such apparatus is a part of the equipment of the Metal Division. (Continued on page 16)

* Editor.

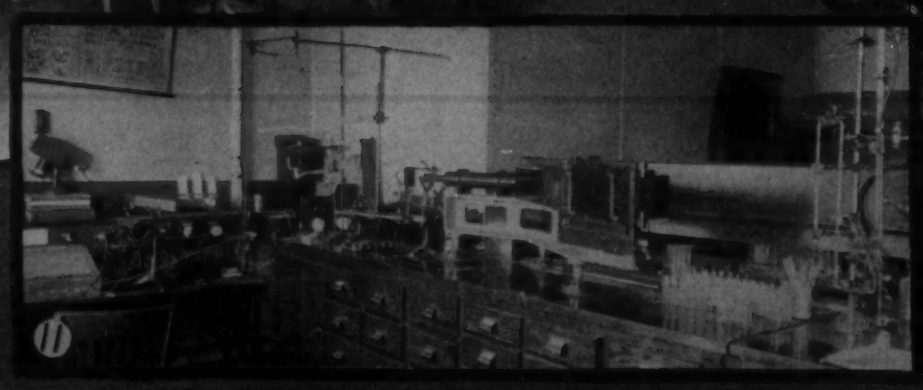


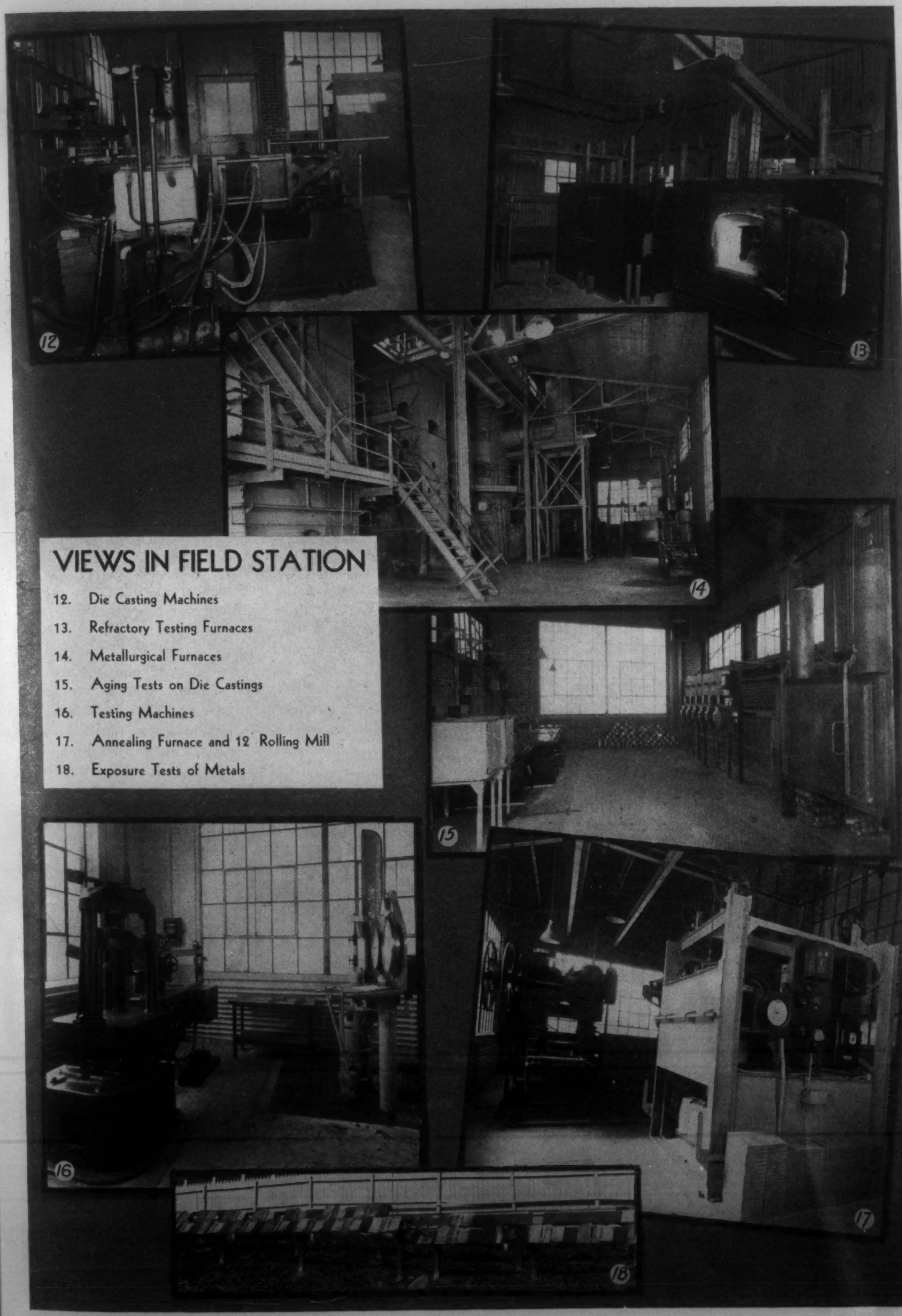




## VIEWS IN MAIN LABORATORY

5. Electroplating Laboratory
6. Thermal Analysis Laboratory
7. Alloy Preparation Laboratory
8. Electrical Conductivity Apparatus
9. Library
10. Instrument Shop.
11. Spectroscopic Laboratory






## VIEWS IN FIELD STATION

12. Die Casting Machines
13. Refractory Testing Furnaces
14. Metallurgical Furnaces
15. Aging Tests on Die Castings
16. Testing Machines
17. Annealing Furnace and 12 Rolling Mill
18. Exposure Tests of Metals

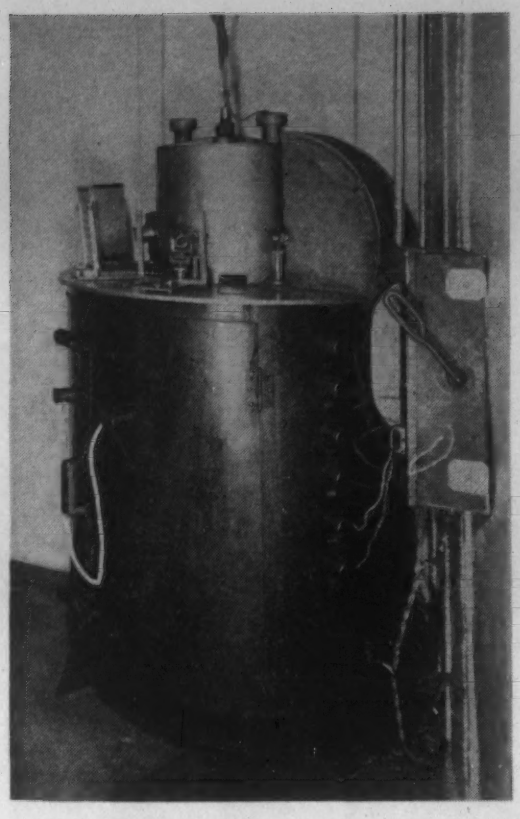


Fig. 2.—X-Ray Equipment

Electrical conductivity determinations play an important part in studying the constitution of alloy systems and apparatus for this work has been carried to an unusually high degree of refinement in these laboratories. Means for controlling the temperature of the specimen at any desired temperature up to 300° C. constitute a feature of this apparatus. The sensitivity of this means of investigation is illustrated by the fact that in handling coarse grained annealed specimens of rolled metal, a special technique is necessary to avoid the slighest bending which would change the conductivity of the strip.

The most modern means of delving into the constitution of metals and alloys is the X-ray diffraction method. Modern equipment safely housed in a lead lined chamber to protect the investigators is provided for this work. A Hadding tube X-ray apparatus is also used to pry even deeper than the molecular arrangement and to study the arrangement of electrons within the atoms.

All of the methods which have been described would be of doubtful value if it were not possible to accurately determine the chemical composition of the alloys studied. While ordinary methods of chemical analysis are usually adequate, there are many important cases where they fail. Here the fortunate development of spectroscopic methods of quantitative analysis have made possible the accurate and rapid determination of amounts of impurities and alloying metals beyond the reach of the ordinary methods. A Spectrographic Laboratory, devoted entirely to this work, makes hundreds of such determinations each month.

A Physical Testing Laboratory is, of course, an essential part of any research organization and the heavy machines required have been located in a specially designed building located at the Research Field Station. In addition to the usual tensile, impact, Brinell and scleroscope testing equipment, special testing machines for testing bending properties, temper and ductility have been developed to meet the particular requirements of work with zinc.

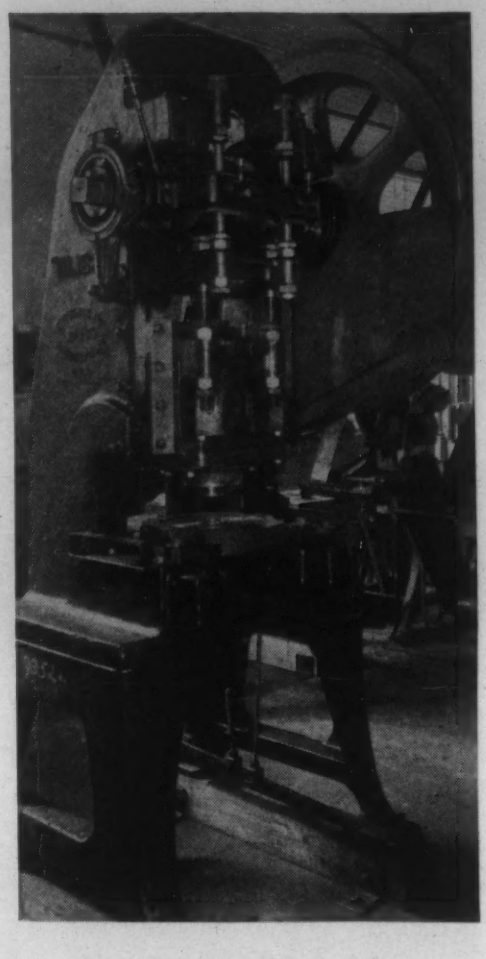


Fig. 3.—Press for Drawing Tests

When small scale tests reveal an alloy of unusual properties, tests are continued on a larger scale. Thus, if the alloy is of interest as an alloy for rolling, tests are continued on a semi-commercial scale in the Experimental Rolling Mill. Here oil fired melting furnaces and thermostatically controlled electric annealing furnaces are used in the casting and heat treatment of the metal.

The ultimate test of the drawing properties of any alloy is an actual drawing operation. Cut and draw, forming and redrawing presses, therefore, form an important part of the testing equipment connected with the Experimental Rolling Mill.

An alloy which appears to have possibilities as a die casting alloy is at once made up in sufficient quantity to charge a small commercial die casting machine. This, in addition to providing information about the

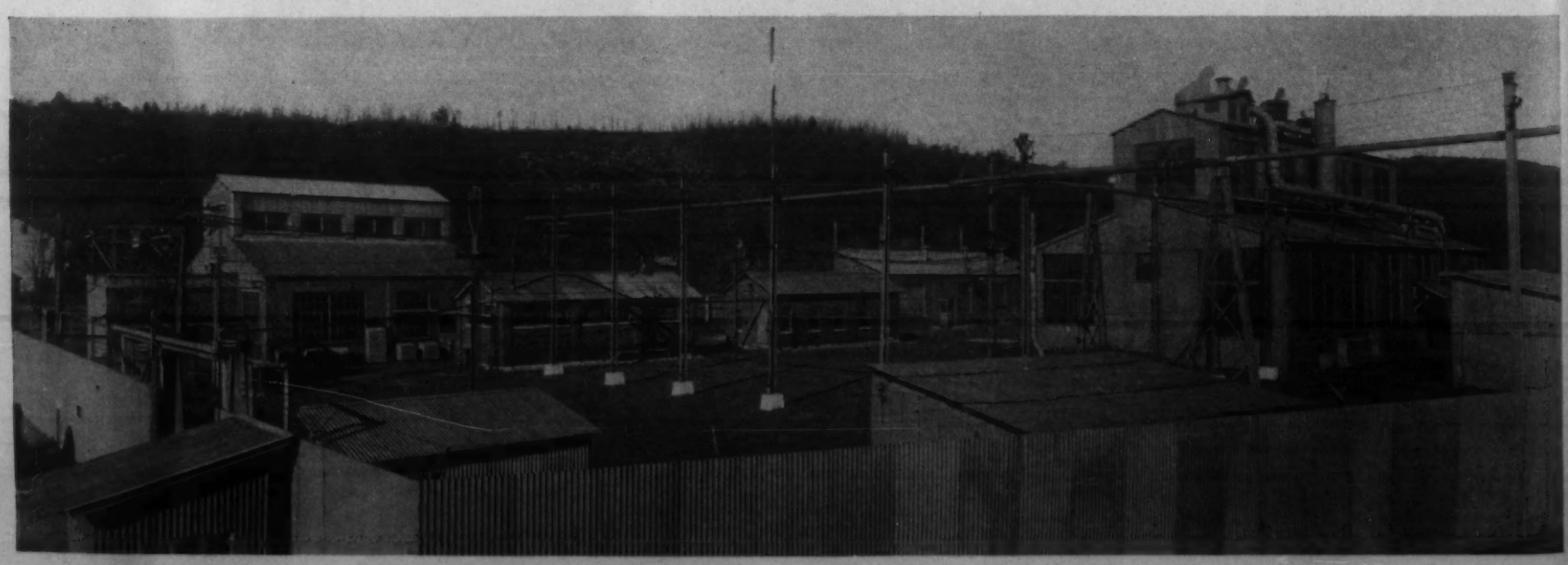


Fig. 4.—Field Station

casting properties, supplies tensile and impact specimens for exhaustive tests on the physical and chemical properties which are of importance in a die casting.

The aging properties of these die cast specimens in both dry and moist atmospheres are determined by exposure ranging from days to many months under automatically controlled conditions in a battery of furnaces devoted to this work.

Both articles fabricated from rolled metal and those die cast are in a large number of cases finished by electroplating. Electroplating on any base metal offers problems peculiar to that metal and a laboratory is consequently provided and suitably equipped for studying the plating of zinc articles.

A problem which is related in a practical way to the finishing of metals is their corrosion resistance and part of the necessary work of the Metal Research Division is a study of the corrosion resistance of rolled and cast zinc both unfinished and plated and also of zinc coatings on iron and steel. Innumerable laboratory tests have been proposed and tried by various investigators to learn in a short time what will happen in years of exposure under service conditions.

The greater part of the efforts of this laboratory, however, are confined to studying what actually does happen in service. To this end a great many outdoor exposure tests under a wide variety of climatic conditions are constantly in progress. The photograph shown represents a part of a series of tests on zinc coatings near Palmerton. Tests of this character have been in progress for a number of years and are yielding information of the greatest interest and value.

This description would be obviously incomplete if in conclusion mention were not made of the service organization which provides certain of the tools which are needed by groups of workers in all of the branches of the research work. Accounting, clerical, stenographic and photographic services are centralized. A completely equipped instrument shop provides for the rapid construction and alteration of the special equipment and apparatus on which the work depends. An extensive library, in charge of trained librarians, is at the disposal of all research workers. Engineering service and advice is provided by engineers attached to the Research Division and, when required, by the Engineering Department of the company. Finally, the vital work of locating and selecting men is also centralized as much as possible in the hands of a trained Personnel worker.

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**Professor Arne Fredrik Westgren** will be the Annual Lecturer for The Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers, February 16 to 21, 1931, in New York.

Arne Fredrik Westgren

Arne Fredrik Westgren was born July 11, 1889, at Årjeng in the province of Wermland, Sweden, and was educated at the State Colleges in Stockholm and Upsala (1900–1907). He also studied at Upsala University (1907–1915), where he took his doctor's degree in 1915. His doctor's work was performed under the guidance of Professor The Svedberg. During 1915 and 1916 he carried on his studies alternately at the universities of Upsala and Göttingen. In Germany he worked under the leadership of Prof. Richard Zsigmondy.

In 1917 he was appointed lecturer in physical chemistry at the University of Upsala but left that position at the beginning of 1918, when he became metallographer at the S.K.F. Ball Bearing Co. in Gothenburg. At the beginning of 1921 he was made assistant at the newly erected Institute of Metallography in Stockholm and served in that position until 1927 when he was appointed Professor of General and Inorganic Chemistry at the University of Stockholm (Stockholms Högskola).

Before 1918, Prof. Westgren's scientific work dealt mainly with the Brownian movement and his doctor's work consisted of a determination of the Avogadro number through studies of the sedimentation equilibrium in gold colloids.

In 1919, at the Institute of Prof. Manne Siegbahn, Dr. Westgren carried out an investigation on the crystal structure of the modifications of iron. Since that time he has busied himself with X-ray investigations of alloys at the University of Stockholm and has published a number of papers on that subject. Most of the latter work has been done in collaboration with P. Phragmén. During the last five years Prof. Westgren has been Secretary of the Nobel Committees for Physics and Chemistry.

When the Annual Lecture is given by a distinguished foreigner, it is customary to have him talk in various metallurgical centers. In conformity with this custom, Dr. Westgren is to speak on the Crystal Structure of Ordinary and Alloyed Steels, Structural Analyses of Alloys, and Crystal Structure and Atomic Properties of Alloys Containing Transition Elements. One or more of these lectures will be given in Chicago, Cleveland, Columbus, New Haven, Pittsburgh and Washington, beside the American Institute of Mining and Metallurgical Engineers' lecture in New York.

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**Ralph S. MacPherran,** chief chemist of Allis-Chalmers Mfg. Co., Milwaukee, and one of the outstanding metallurgists in the field of cast iron, has been awarded the J. H. Whiting gold medal of the American Foundrymen's Association for his many valued contributions to the foundry industry. The award was unanimously voted by the A.F.A. Board of Awards recently, and has since been approved by the Board of Directors.

The J. H. Whiting gold medal is one of four awards made by the A. F. A. for the purpose of encouraging and stimulating meritorious achievements in the foundry industry. Granting of these awards is vested in a permanent and self-perpetuating Board of Awards consisting of the seven living past presidents of the Association, the chairman being the last president.

Mr. MacPherran, for many years a prominent and active contributor to the committee work of the A. F. A. and the A. S. T. M., has been identified with the iron and steel industry for nearly thirty years. Born Feb. 1, 1871, he received a technical education at the University of Wisconsin and University of Michigan, graduating from the latter institution in 1892 with a B.S. degree in chemistry. On leaving college he was associated for three years with the Illinois Steel Co. at the Joliet and South Chicago, Ill., works, and became connected with the former E. P. Allis Co. of Milwaukee in 1895. Leaving that firm in 1907, he spent one year with the J. I. Case Threshing Machine Co., Racine, Wis., before returning to the newly formed Allis-Chalmers Mfg. Co., Milwaukee. Mr. MacPherran has been associated with the Allis Chalmers organization ever since, in charge of their chemical and physical laboratories.

Mr. MacPherran is especially noted for his coöperation in the committee activities of several technical organizations and for the assistance he has given many young metallurgists in the field of cast iron. He is a member of the A. F. A., A. S. T. M., A. S. S. T., American Chemical Society and International Society for Testing of Materials.

# Note on the Effect of Various Annealing Temperatures on Cold Worked Low Carbon Steel

By H. E. Publow*

OF late years the cold drawing of low carbon steel into various shapes has assumed vast commercial importance. The cold working of steel is generally accompanied by an increase in hardness. Sometimes, as in the case of automobile brake drums, this increase in hardness is highly desirable. When several forming operations are necessary in order to produce a finished article, an anneal between draws becomes necessary in order to prevent failure. The lower the temperature that can be used for this work the better from a manufacturing standpoint.

There are many theories given to account for the hardening due to cold work. Jeffries and Archer present the following: "Hardness is the resistance to permanent deformation. Metals fail under stress much below their ultimate strength because they are built up of crystals. Decreasing the size of these crystals will increase the hardness." Kataro Honda attributes hardness to two factors: First, "forces acting between the molecules of a substance" and second, "the crystalline structure of the metal." He then goes on to add that "for a given substance having a definite molecular force its hardness increases with the fineness and strained state of the structure." W. Geiss and Van Liempt declare that there are "two theories as to the mechanism of transformation of metal worked in the cold. First (due to Tammann) that the crystals glide over each other in certain characteristic gliding planes. Second, (due to Czochralski) that the actual shape of the lattice is distorted." From the following data the reader can judge how well these results bore out any of the above theories.

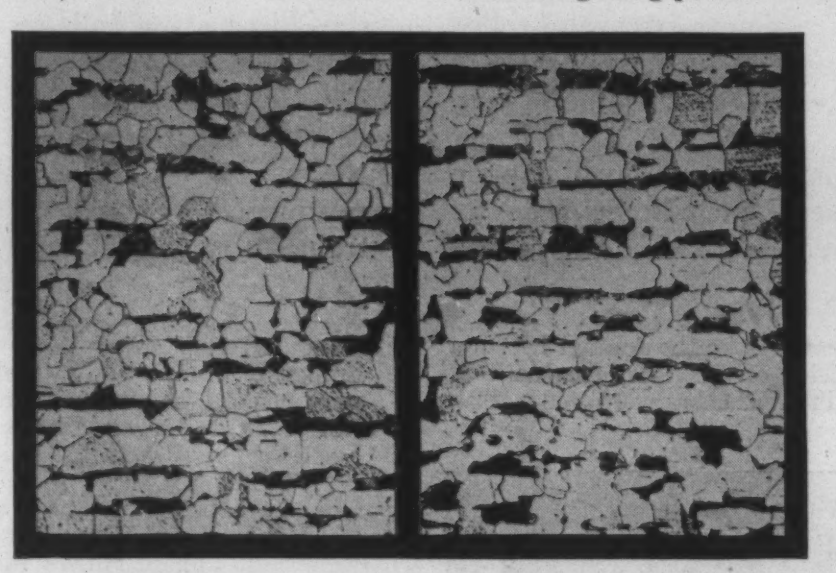

Fig. 1.—Unformed Low Carbon Steel. Magnification 100×. Hardness 60 Rockwell "B" Scale

Fig. 2.—Formed Low Carbon Steel. Magnification 100×. Hardness 90 Rockwell "B" Scale

In a good automobile brake drum which has been formed cold from low carbon steel, the bearing surface of the drum will have increased as much as 30 points Rockwell "B" scale over the raw stock. A study of the microstructure of such a drum showed no deformation of either the ferrite or the pearlite anywhere, even in the fairly sharp bends. Figs. 1 and 2 are micrographs of the formed and unformed steel. The steel in Fig. 1 has a hardness of 60 Rockwell "B" and the steel in Fig. 2, a hardness of 90 Rockwell "B." Although the steel was reduced several thousandths of an inch in cross section in the forming operation, the grains still appear unstrained. Here is a case where we have a marked increase in hardness without an appreciable, or, at least, readily detectable, decrease in size. Even under high magnification, the pearlite appeared perfectly normal.

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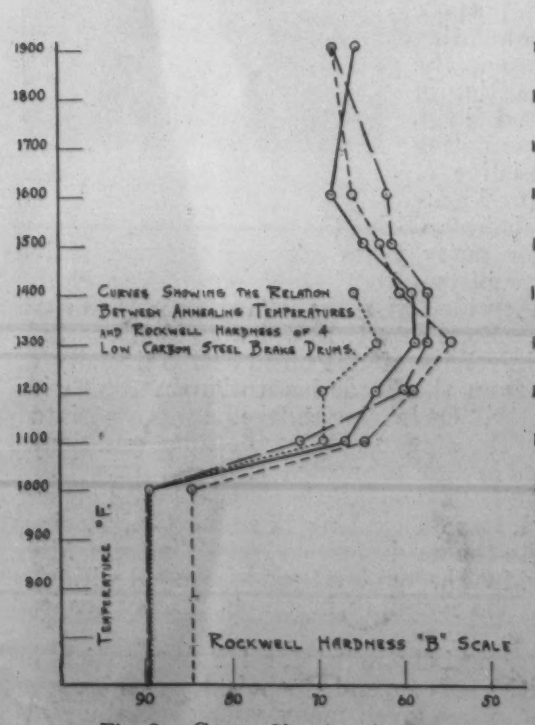


Fig 3.—Curves Showing the Relation between Annealing Temperatures and Rockwell Hardness of 4 Low Carbon Steel Brake Drums

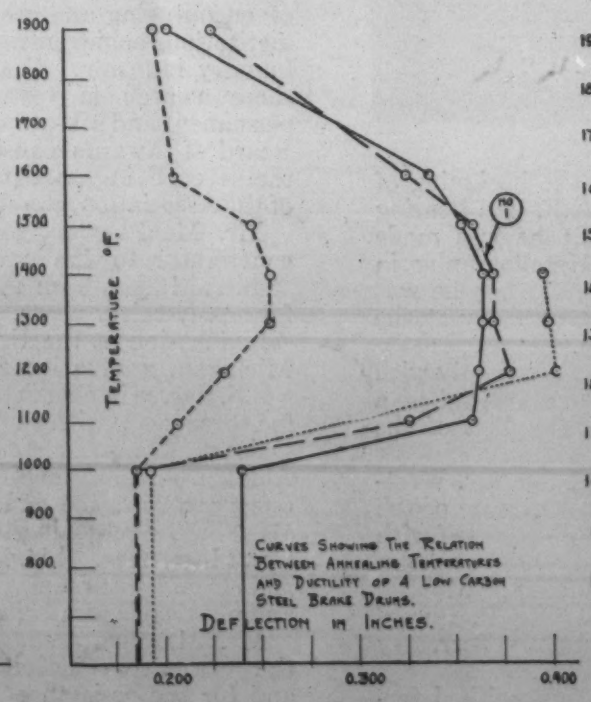


Fig. 4.—Curves Showing the Relation between Annealing Temperatures and Ductility of 4 Low Carbon Steel Brake Drums

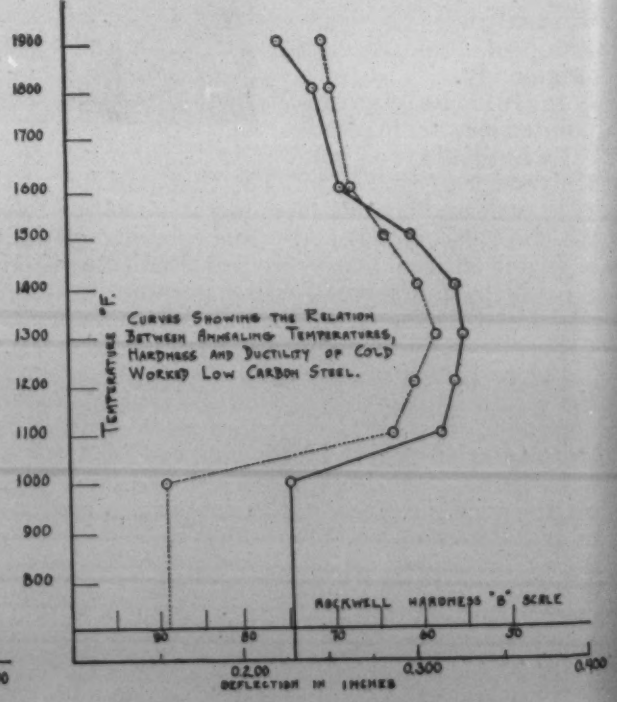


Fig. 5.—Curves Showing the Relation between Annealing Temperatures, Hardness and Ductility of Cold Worked Low Carbon Steel

Although the microscope revealed no change in structure, the steel exhibited some peculiar effects both as regards hardness and ductility when annealed at various temperatures. Several drums were picked at random from a large number. That section of the drum used as a bearing surface and which showed the greatest increase in hardness was carefully removed and cut into test samples about 2″ square. The steel was low in manganese and ran about 0.2% carbon. A series of short anneals was then run on these test pieces, after which they were tested for both hardness and ductility. The annealing consisted of holding the pieces at the desired temperature for ½ hour and then allowing them to cool with the furnace. At temperatures below 1000° F. there was no change in either hardness or ductility. One would ordinarily expect some softening at this temperature even with such a short anneal. Work on longer anneals is in progress. At 1100° the steel began to soften considerably and at 1300° F. it reached its softest point. As the annealing temperatures were raised the steel became slightly harder. At 1600° F. it hardened about 10 points on the Rockwell "B" scale as compared with the hardness after annealing at 1350°. This is doubtless due to heating above the lower critical temperature. At 1900° F., although the grain was much larger the hardness had changed but little. Some drums showed a slight increase and others a slight decrease in hardness over that obtained at 1600°. The results of the tests made on four drums are given in Fig. 3.

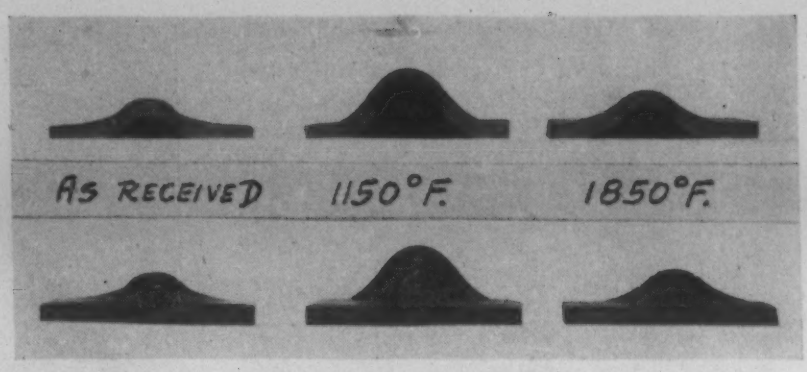


Fig. 6.—Section through 3 Test Pieces Tested for Ductility. Magnification about One Half

Ductility determinations were made on all the test samples. These determinations were made on an Emery-Southwark hydraulic ductility machine. The readings taken were, the deflection at maximum load and the amount of the maximum load. The ductility curves follow quite closely in general shape the hardness curves, as shown in Fig. 4. After being annealed at 1000° F. the deflection was no more than shown in the untreated steel. Above 1000° F. the deflection at maximum load increased rapidly and reached a maximum between 1250° and 1400° F. Above 1400° F. there was a decrease in ductility. At 1900° the deflection at maximum load was but little better than in the hardened steel. Curve No. 1, Fig. 4 is typical of many of the steels which were tested. In this case the cold worked steel gave a deflection of 0.180″ at maximum load. After being heated to 1200° F. the deflection had jumped to 0.375″ or an increase of over 100%. At 1900° F. it had dropped to 0.230″. A treatment at 1600° did not give as satisfactory results as one at 1300°. Fig. 5 gives the average obtained on five drums for both ductility and hardness.

Figs. 6–9 give some idea of the difference in ductility obtained by the various heat treatments. Even at this low magnification it can be seen that the sample annealed at 1900° F. has a very coarse grain.

The author has no explanation to offer at present for the hardening and loss of ductility at the higher annealing temperatures. There is, of course, a possibility that a precipitation-hardening effect may be involved, and that the short anneals produce an accelerated aging effect. The maximum softness and ductility seemed to occur around, probably just below, the lower critical temperature. Up to the point of maximum softness there was no change in grain size. The changes then, must be due to reactions within the grains themselves, which the microscope does not reveal. Low carbon steel has often been considered a rather simple alloy and its structural changes well understood. The results obtained in these experiments show that there is still room for a great deal of study on this common metal.

Fig. 7.—(*Above*) Section through a Sample of Hardened Stock Tested for Ductility. Magnification about 4×

Fig. 8.—(*At right*) Section through a Sample of Hardened Stock Annealed at 1150° F. for ½ Hour. Magnification about 4×

Fig. 9.—(*Below*) Section through a Sample of Hardened Stock Annealed at 1850° F. for about ½ Hour. Magnification about 4×

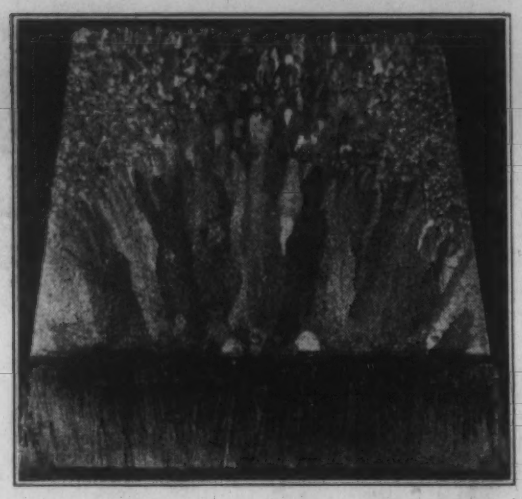

Fig. 1.—Cast Surface of an Ingot of Babbitt of the Approximate Composition: 85% Sn; 7.5% Sb; 7.5% Cu. 1/2 Size. $(NH_4)_2S_x$ Etch

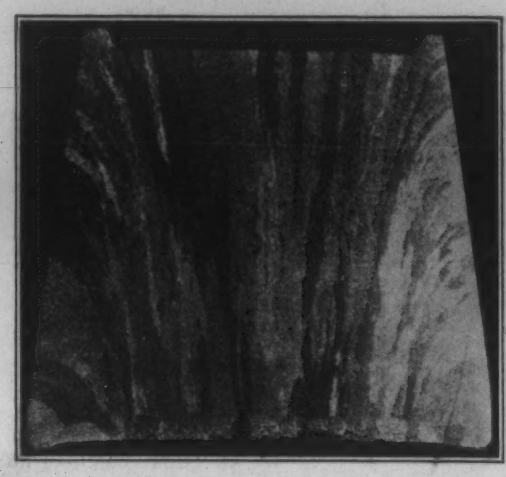

Fig. 2.—Polished Section of the Ingot Shown in Fig. 1. 1/2 Size. $(NH_4)_2S_x$ Etch

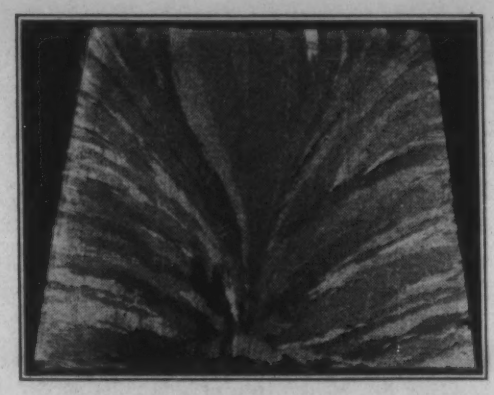

Fig. 3.—Polished Section of Ingot of Babbitt of the Approximate Composition: 91% Sn; 4.5% Sb; 4.5% Cu. Actual Size. $(NH_4)_2S_x$ Etch

# The Macro-Etching of Tin-Base Bearing Metals

By Ernest B. Drake[1]

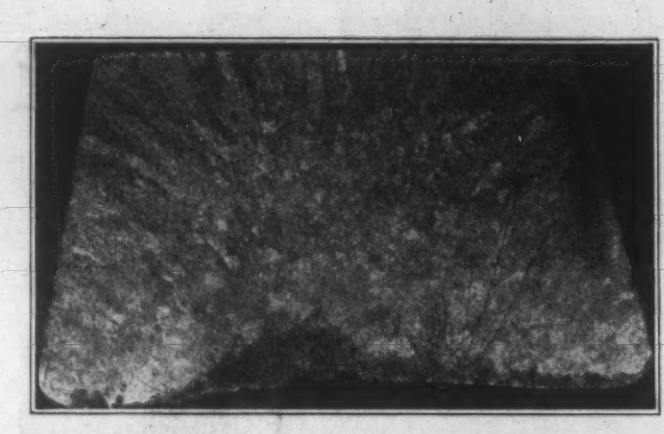

Fig. 4.—Polished Section of Ingot of Babbitt of the Approximate Composition: 83% Sn; 7.5% Sb; 7.5% Cu; 2% Pb. Actual Size. $(NH_4)_2S_x$ Etch

Fig. 5.—Polished Section of Ingot of the Approximate Composition: 90% Sn; 10% Cu. Actual Size. $(NH_4)_2S_x$ Etch

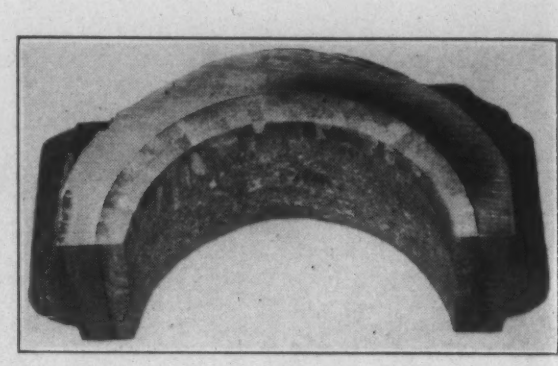

Fig. 6.—Bearing Surface of a Connecting-Rod Babbitt: 85-7.5-7.5. Cast with the Gate Extending Entirely around the Bearing. 1/2 Size. $(NH_4)_2S_x$ Etch

This investigation was begun at the suggestion of Mr. L. A. Danse[2] and was carried out in the metallurgical laboratory of the Cadillac Motor Car Co., Detroit, Mich., and with the coöperation of his staff and that of the engineering and manufacturing departments. The author's particular thanks are due Mr. Ludwik Sliwowski[3] and Mr. R. E. Cordes[4] for their kind coöperation, and to Mr. R. W. Roush[5] for his help in making the macro-photographs.

It was believed a macro-examination of bearing metals, particularly the tin-base alloys, such as are used where heavy loads and high speeds are necessary, as for example connecting-rod bearings, main bearings, etc., in automobile and air craft motors might be of some value in pointing out:

(1) Crystal size of the alloy.

(2) Distribution of large and small crystals.

(3) A correlation between micro- and macro-structure; with the hope that the macro-examination might reveal a critical size of crystals best adapted to the severe demands made upon bearing metals in connecting-rod and main bearings.

(4) Possible improvements in casting technique.

(5) It was further thought a macro-examination of cast babbitt metal might reveal why bearing failures start at particular locations on the bearing surfaces, and it was hoped suitable changes in casting practice might be effected to eliminate in part, at least, the failures in bearing metals observed in connecting-rod bearings which had been subjected to heavy loads and high speeds over long periods of time in dynamometer and road tests of automobile and other motors.

The investigation was started with tin-base babbitts in mind having the approximate composition: 85% Sn; 7.5% Sb; 7.5% Cu. It is generally believed this type of cast babbitt is composed of the hard constituents SnSb and CuSn in various states of dispersion, depending upon the composition of the alloy, the casting temperature, the rate of cooling as affected by the amount of metal cast, method of casting, use of chills, etc. It is also believed these hard particles are imbedded in a tin-rich eutectic and the $\delta$-solid solution.[6]

[1] Assistant Professor, Chemical Engineering, The College of the City of Detroit.
[2] Superintendent, Metallurgical Department, Cadillac Motor Car Co.
[3] Metallographist, Cadillac Motor Car Co., Detroit, Mich.
[4] Chief Chemist, Cadillac Motor Car Co., Detroit, Mich.
[5] Metallurgist, Cadillac Motor Car Co., Detroit, Mich.

[6] O. W. Ellis & G. B. Karelitz. A Study of the Tin-Base Bearing Metals, Spring Meeting, American Society of Mechanical Engineers, May 14–17, 1928.

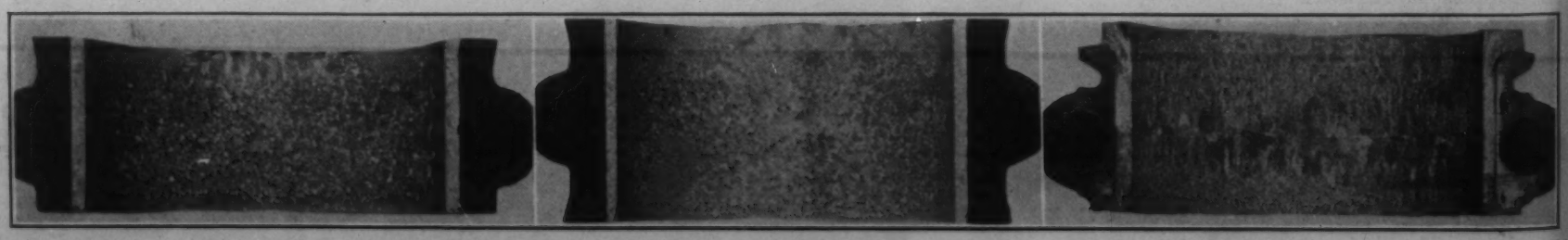

Fig. 7.—Connecting-Rod Cap with Die-Cast Babbitt: 85% Sn; 7.5% Sb; 7.5% Cu. Narrow Gate at Top. Reduced 1/3. $(NH_4)_2S_x$ Etch

Fig. 8.—Die-Cast Connecting-Rod Cap, Not Finish Machined. Gate at Top. Babbitt: 85% Sn; 7.5% Sb; 7.5% Cu. Reduced 1/3. $(NH_4)_2S_x$ Etch

Fig. 9.—Centrifugally Cast Connecting-Rod Cap, Not Finish Machined. Babbitt: 85% Sn; 7.5% Sb; 7.5% Cu. Reduced 1/3. $(NH_4)_2S_x$ Etch

**Fig. 10.**—Section of Connecting-Rod Cap, Die-Cast, Gate on Lower Side. Note Decrease in Crystal Size in Passing Away from Gate Side. Babbitt: 85% Sn; 7.5% Sb; 7.5% Cu. 2½ ×. $(NH_4)_2S_x$ Etch

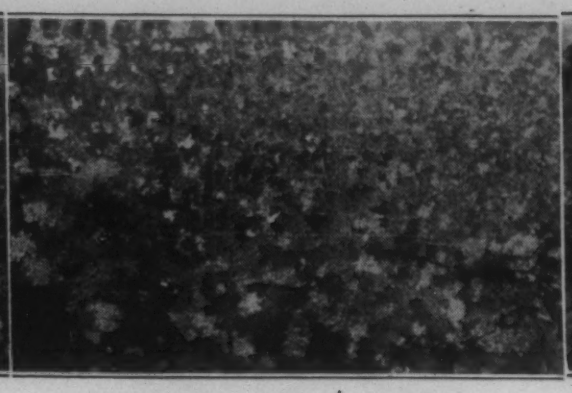

**Fig. 11.**—Section of Connecting-Rod Cap Which Failed in Test Run. Die-Cast, with Gate on Lower Side. Babbitt: 85% Sn; 7.5% Sb; 7.5% Cu. 2½ ×. $(NH_4)_2S_x$ Etch

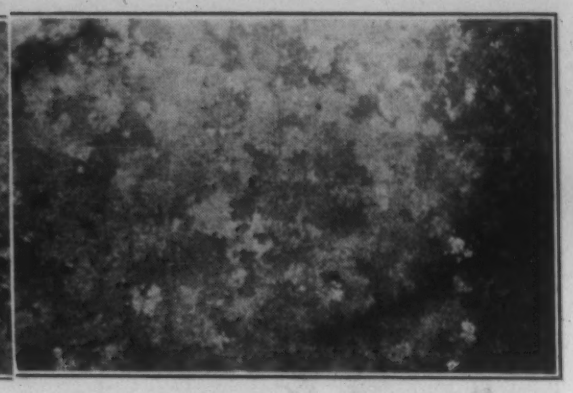

**Fig. 12.**—Section of Connecting-Rod Cap Which Failed in Test Run. Die-Cast, With Gate on Lower Side. Babbitt: 85% Sn; 7.5% Sb; 7.5% Cu. 2½ ×. $(NH_4)_2S_x$ Etch

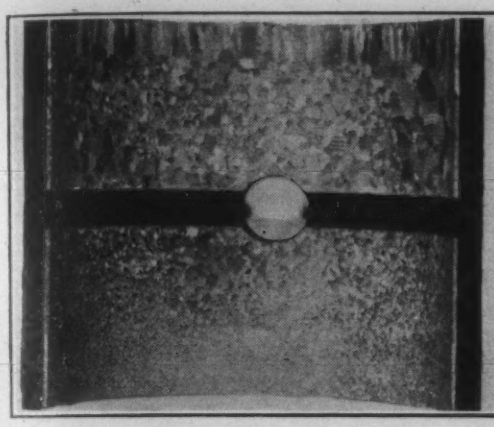

**Fig. 13.**—Die-Cast Steel-Backed Main Bearing, with Gate on Top. Babbitt: 85% Sn; 7.5% Sb; 7.5% Cu. Reduced ¼. $(NH_4)_2S_x$ Etch

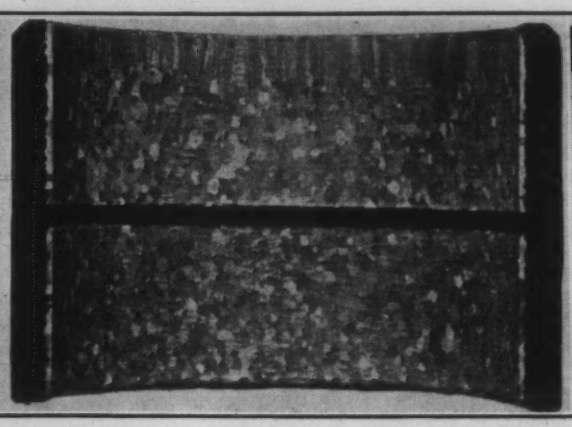

**Fig. 14.**—Centrifugally Cast, Bronze-Backed Main Bearing. Babbitt: 85% Sn; 7.5% Sb; 7.5% Cu. Reduced ¼. $(NH_4)_2S_x$ Etch

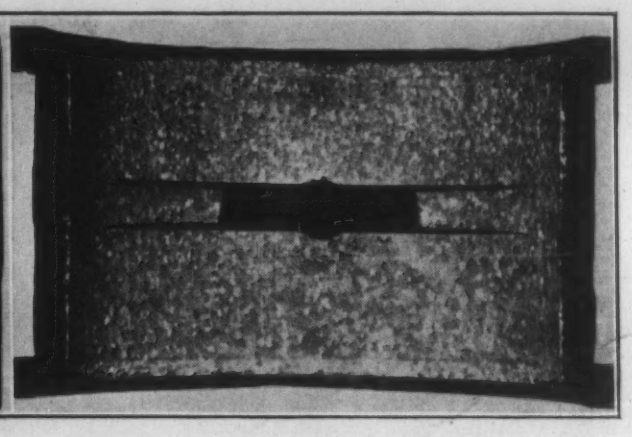

**Fig. 15.**—Centrifugally Cast, Bronze-Backed Main Bearing. Babbitt: 85% Sn; 7.5% Sb; 7.5% Cu. Reduced ¼. $(NH_4)_2S_x$ Etch

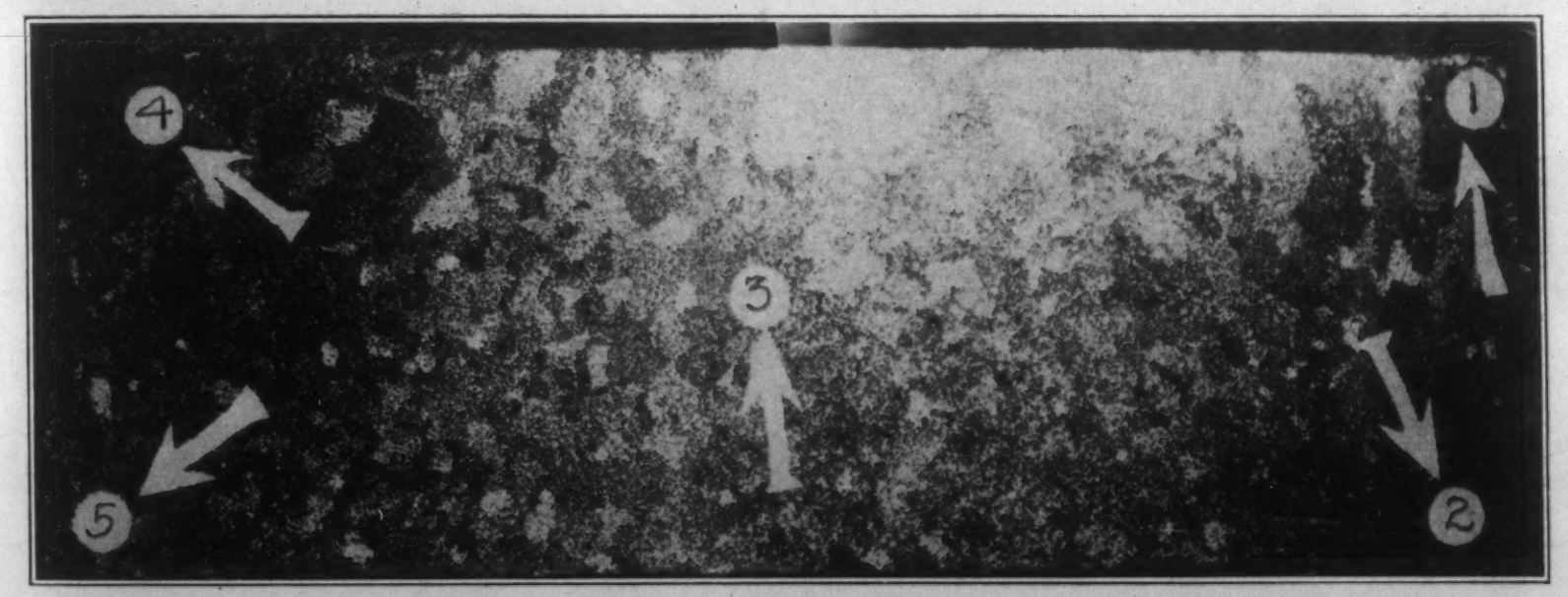


**Fig. 16.**—Section Cut from Specimen Shown in Fig. 8. 4 ×. $(NH_4)_2S_x$ Etch

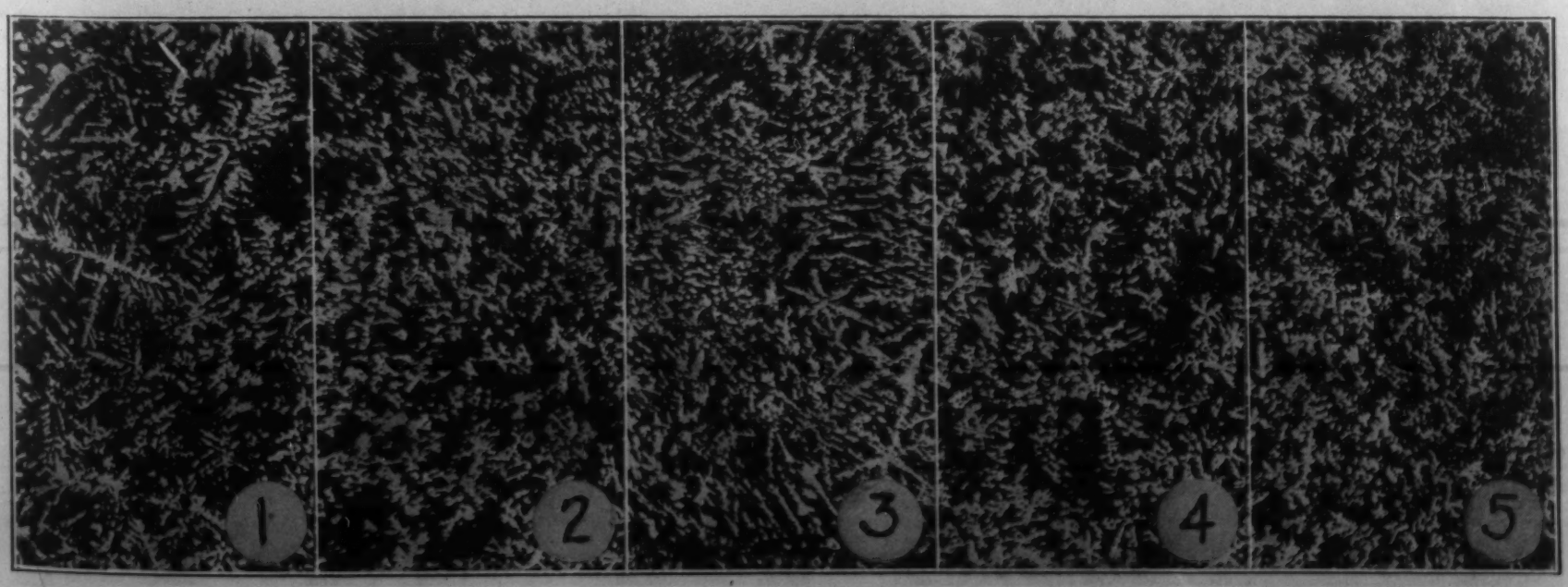


**Fig. 17.**—Photomicrographs of Section Shown in Fig. 16. 100 ×. $FeCl_3$ Etch. The Large Crystals at Points 1 and 3 in Fig. 16 Show Large Stars and Needles of CuSn Imbedded in the Eutectic (Dark Areas) and the δ-Solid Solution (Light Areas), Whereas the Medium Sized Crystals at Points 2, 4, and 5 of Fig. 16 Show Fine, Uniformly Distributed CuSn Needles in the Eutectic (Dark) and δ-Solid Solution (Light) Areas. Note the Absence of SnSb Cubes

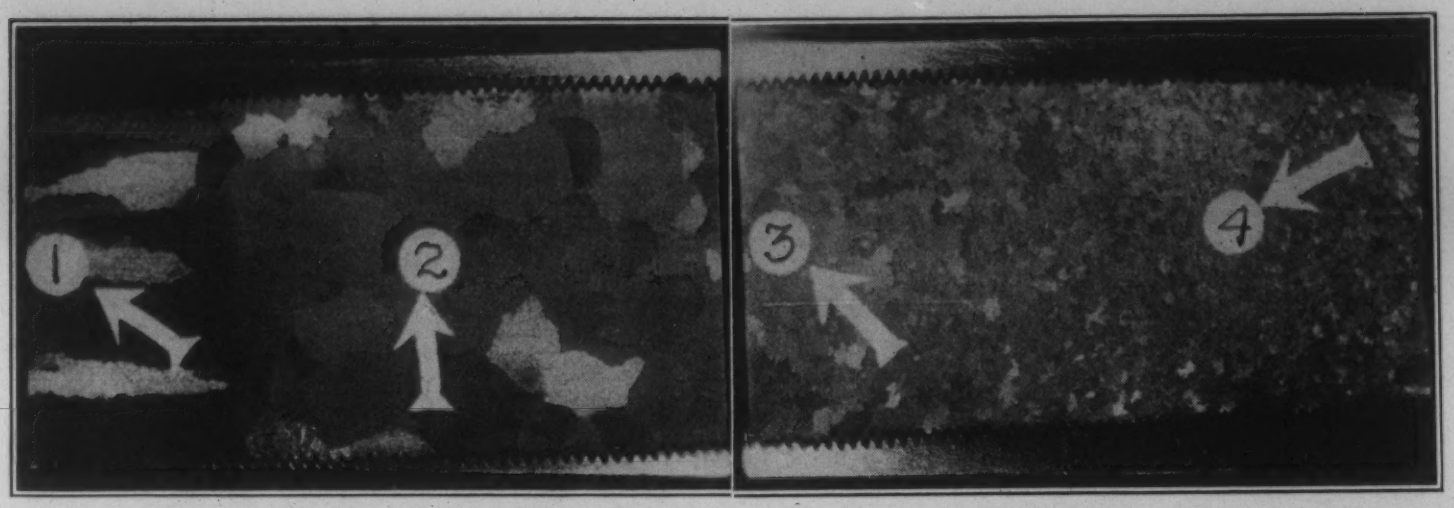


**Fig. 18.**—Section Cut from Specimen Shown in Fig. 13. 3¼ ×. $(NH_4)_2S_x$ Etch

**Fig. 19.**—Photomicrographs of Section Shown in Fig. ~~20~~ 18. 100 ×. $FeCl_3$ Etch. The Long Crystals at 1 in Fig. 18 Show Large Stars and Needles of CuSn and Large Areas of Eutectic (Dark), and a Small Amount of δ-Solid Solution (Light Areas). At 2 the Large Polygonal Crystals Show More Massive but Smaller Stars and Needles of CuSn, a Decrease of Eutectic Areas (Dark) and an Increase of the δ-Solid Solution Areas (Light). At 3 the Medium Sized Polygonal Crystals Show a Less Massive and Finer Distribution of the CuSn Needles, Less Eutectic Areas (Dark) and About the Same δ-Solid Solution Areas (Light). At 4 the Finest Crystals Show the Finest CuSn Needles and About the Same Eutectic (Dark) and δ-Solid Solution (Light). Note Entire Absence of SnSb Cubes

**Fig. 20.**—Section Cut from Specimen Shown in Fig. 9. 5 ×. $(NH_4)_2S_x$ Etch

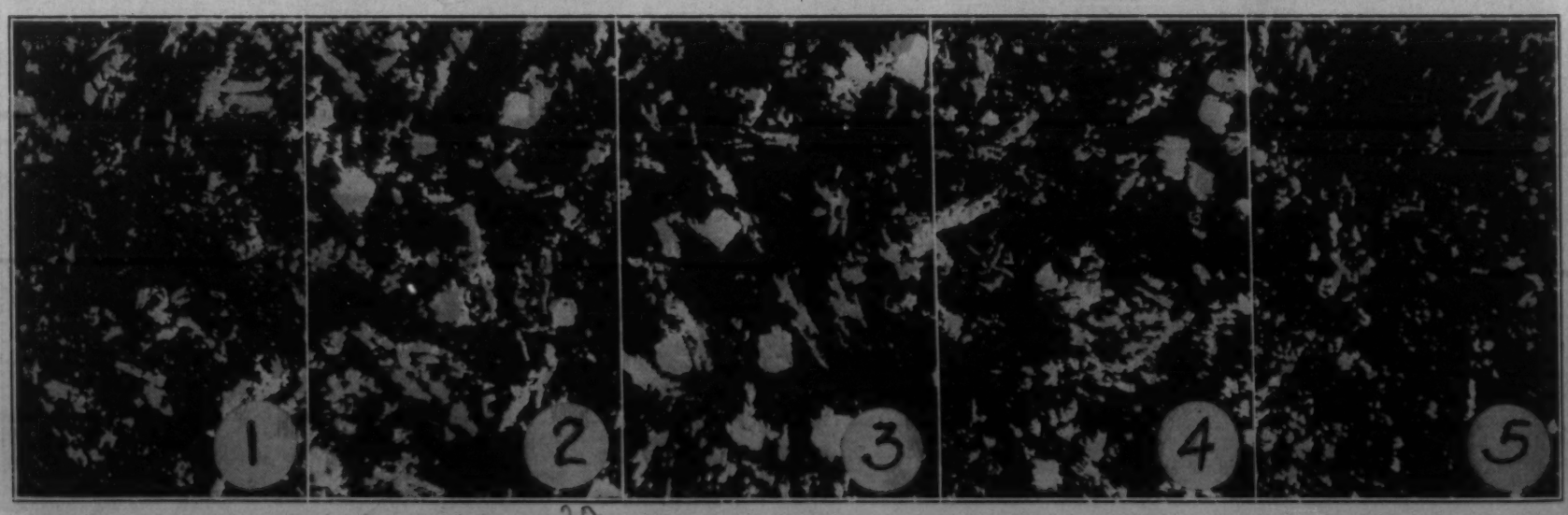


**Fig. 21.**—Photomicrographs of Section Shown in Fig. ~~18~~ 20. 100 ×. $FeCl_3$ Etch. The Large Crystals in the Center of Fig. 20 Show Large SnSb Cubes and Massive CuSn Needles Surrounded by Large Eutectic (Dark) Areas Whereas the Small Crystals in Fig. 20 at the Ends of the Specimen Show Very Small SnSb Cubes and Much Finer CuSn Needles Imbedded in the Eutectic (Dark)

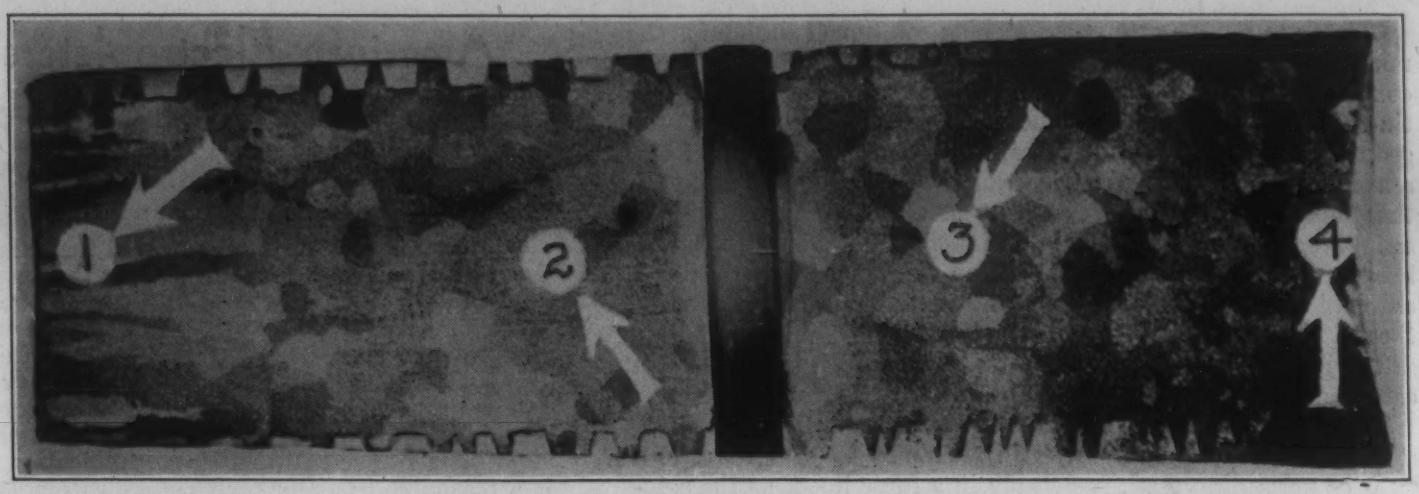


Fig. 22.—Section Cut from Specimen Shown in Fig. 14. 3½ ×. $(NH_4)_2S_x$ Etch

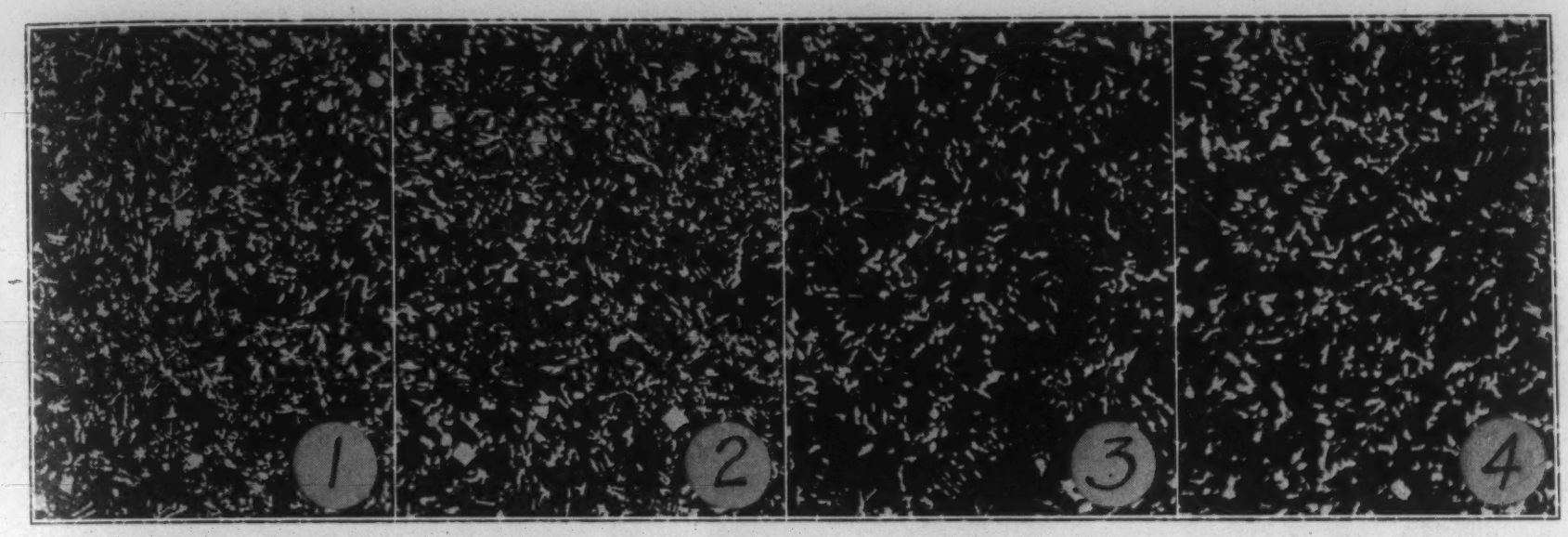


Fig. 23.—Photomicrographs of Section Shown in Fig. 22. 100 ×. $FeCl_3$ Etch. The Long Crystals in Fig. 22 at 1 Show a Large Amount of Dark Areas (Eutectic) and a Few Small SnSb Cubes. At 2 the Medium Sized Polygonal Crystals of Fig. 22 Show a Uniform Distribution of the CuSn Needles and Small Cubes of SnSb in the Eutectic (Dark). At 3 the Smaller Polygonal Crystals of Fig. 22 Show More Massive but Fewer CuSn Needles in the Eutectic Ground-Mass (Dark) with a Few Small Cubes of SnSb. At 4 the Smallest Polygonal Crystals of Fig. 22 Show a Finer Distribution of the CuSn Needles Uniformly Distributed in the Ground-Mass of the Eutectic (Dark) and no SnSb Cubes

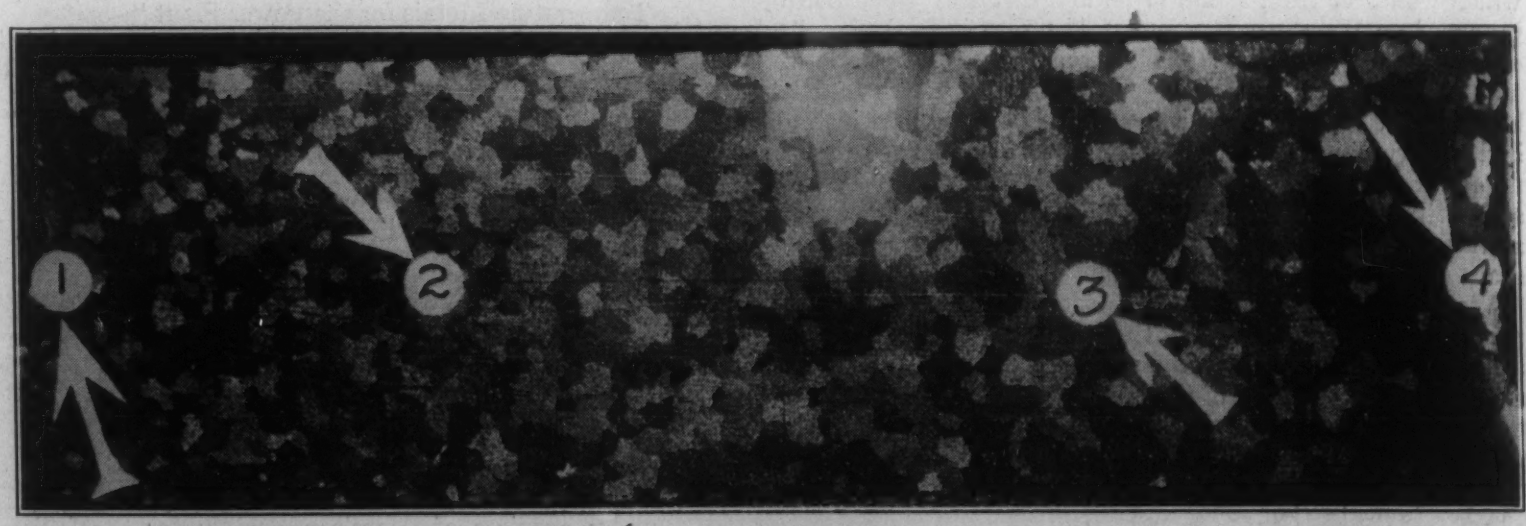


Fig. 24.—Section Cut from Specimen Shown in Fig. 15. 3 ×. $(NH_4)_2S_x$ Etch

Fig. 25.—Photomicrographs of Section Shown in Fig. 24. 100 ×. $FeCl_3$ Etch. In Fig. 24 We Have a Uniform Crystal Size with Slightly Larger Crystals the Center of the Photograph. The Microphotographs Show a Uniform Distribution of CuSn Needles and SnSb Cubes in a Ground-Mass of Eutectic (Dark) and -Solid Solution (Light) Areas

There are a number of good etching solutions suitable for the micro-examination of tin-base babbitts to reveal the above named constituents, but so far as we know none would macro-etch the tin-rich eutectic and the δ-solid solution. Bearing in mind the ground-mass we wished to reveal was composed largely of tin, a number of solutions were tried which were known to react with that metal. The most satisfactory solution we have found to date for high tin babbitts is ammonium sulphide, $(NH_4)_2S_x$, known as ammonium poly-sulphide, ammonium sulphide (yellow) ammonium sulphide (dark solution), etc. The solution must be the poly-sulphide, as *light* yellow ammonium sulphide, the normal salt, will not work. If the light yellow sulphide is on hand, it can be made to work by saturating it with flowers of sulphur.

The solution is best used cold and without dilution, the specimens being completely immersed in it for 20 to 30 minutes in a glass or porcelain vessel, preferably in a fume hood, as the solution has a bad, nauseating odor. After etching, the specimen is removed and the accumulation of brown powder is gently swabbed off under running water with a wad of cotton. If the deposit sticks, as for example on a concave surface, the specimen is again immersed in the reagent for a few minutes, when the deposit will generally be easily removed.

The solution works well on all high tin babbitts; but in the case of low tin and high copper babbitts it has been found best to follow the etching with $(NH_4)_2S_x$ by immersion in a freshly prepared solution composed of equal parts $H_2O_2$ and concentrated $NH_4OH$. If the macro-etched specimen cannot be photographed within a few hours of the time of etching, the above procedure will help to keep the specimen from becoming dark and indistinct. It is best however, to photograph soon after etching.

We have tried $(NH_4)_2S_x$ solution on the following:

| Sn | Sb | Cu | Pb | Ni | Results |
|---|---|---|---|---|---|
| 85 | 7.5 | 7.5 | .. | .. | Good |
| 82.5 | 7.5 | 7.5 | 2.5 | .. | Good |
| 91 | 4.5 | 4.5 | .. | .. | Good |
| 75 | 8.0 | 16.0 | 0.25 | 0.75 | Good |
| 90 | ... | 10.0 | .. | .. | Good |
| 83 | 4.0 | 13.0 | .. | .. | Good |
| Commercially pure antimony | | | | | Good |
| Commercially pure tin | | | | | Corrodes it but does not appear to reveal a crystalline structure |
| Commercially pure lead, zinc and cadmium. No apparent action. | | | | | |

It was found that ammonium sulphide etched babbitts well which were free from a film of oil and dirt and which had been prepared on Hubert paper No. 00, but that it worked well also on the cast surface of ingots which were reasonably smooth. It also worked very well on finish-machined surfaces of babbitt bearings without any polishing, and likewise upon bearings which had been run in motors, without any polishing. The reagent has no apparent effect on the polished surface of steel backs, which are left bright and shiny. Thus the bond may be observed on sections of bearings. Bronze is quickly blackened which makes a sharp contrast with the etched babbitt, which is left light colored.

We have no explanation for the etching of babbitt with this reagent. But from the fact the reagent blackens bronze and also etches pure antimony, the cast surface of which strongly resembles the cast surface of the ingot of babbitt (after etching), it may be that the tin-rich eutectic crystals are outlined by a selective blackening much the same as pearlite is revealed at high magnification by alcoholic nitric acid. This should be the subject of another investigation.

It is to be noted that in the photographs of the centrifugally cast main- and connecting-rod bearings we have cubes of SnSb appearing in the micrographs and that they are practically absent in the photographs of the die-cast bearings.

SUMMARY

A method for macro-etching tin-base babbitts of various compositions has been suggested.

The failures in connecting-rod bearings which have been run in test engines appear most often in the finely crystalline babbitts near the joint.

The macro-etched babbitts indicate fairly well the size and distribution of the micro-constituents which may be expected.

Centrifugally cast main- and connecting-rod bearings show SnSb cubes which are generally associated with a smaller number of CuSn needles than when the SnSb cubes are absent, all imbedded in a ground-mass of tin-rich eutectic when the babbitt is of the type: 85% Sn; 7.5% Sb; 7.5% Cu.

The die-cast main- and connecting-rod bearings show no SnSb cubes but do show a larger amount of CuSn needles imbedded in a ground-mass of tin-rich eutectic and δ-solid solution when the babbitt is of the type: 85% Sn; 7.5% Sb; 7.5% Cu.

# American Electroplaters' Society Conference on Electroplating Standards

All interested persons are invited to attend a conference on electroplating standards to be held at the Palmer House, Chicago, January 17, 1931, at 9:00 A.M., under the auspices of the Chicago Branch and the Research Committee of the American Electroplaters' Society. Those who expect to attend, are requested to notify Jacob Hay, 6920 Ottawa Avenue, Edison Park, Chicago, Illinois, so that necessary arrangements may be made.

The purpose of the conference is to include both the materials used in the plating industry and the plated products, and to consider in each case (*a*) whether a specification is needed, (*b*) what is a reasonble basis for such a specification, (*c*) whether sufficient information is now available to prepare at least a tentative specification, (*d*) whether any existing specifications meet the need; and (*e*) to take steps toward the preparation and adoption of suitable specifications by the American Electroplaters' Society, in coöperation with other interested organizations.

# A. F. A. Regional Meeting At Birmingham

The American Foundrymen's Association will hold a regional meeting at the Tutwiler Hotel, Birmingham, Alabama, January 20, with sessions on high test cast iron, cupola practice, practical sand control and foundry costs. January 21 will be devoted to plant visits.

# Metallurgical Papers at Midwest Power Conference

At the 5th Midwest Power Engineering Conference at the Hotel Stevens, Chicago, Feb. 10–13, there will be a luncheon meeting of the Fuels Division of the American Society of Mechanical Engineers on Wednesday, Feb. 11, presided over by C. C. Whittier, of R. W. Hunt Co., at which L. W. Spring, Chief Chemist and Metallurgist of the Crane Co., will discuss "High Temperature Metals for the Power Plant."

Other papers of metallurgical interest are scheduled as follows: Wednesday, Feb. 11, morning, "Trends in Steam Turbine Development," by A. D. Bailey, Commonwealth Edison Co.; afternoon, "Electric Arc Welding in the Power Plant," by W. H. Zorn, Detroit Edison Co.; and a session Thursday morning, Feb. 12, on "Water Problems of the Power Plant Industry" in which corrosion will be sure to receive attention.

The Power Show will be held at the Coliseum, Feb. 10–14.

# Calendar of Meetings

**American Institute of Electrical Engineers,** Annual Winter Convention, New York, N. Y., Jan. 26–30, 1931.

**American Society of Mechanical Engineers,** Fourth National Fuels Meeting, Chicago, Ill., Feb. 10–24, 1931.

**Fifth Midwest Power Engineering Conference.**

**Midwestern Power and Engineering Exposition.**

**Second Western Metal Congress,** Auditorium, San Francisco, under auspices of American Society for Steel Treating, Feb. 16–20, 1931.

**American Chemical Society,** 81st Meeting, Indianapolis, Ind., Mar. 30–Apr. 3, 1931.

**American Electrochemical Society,** Hotel Tutwiler, Birmingham, Ala., Apr. 23–25, 1931.

**Thirteenth Exposition of Chemical Industries,** Grand Central Palace, New York, N. Y., week of May 4th, 1931.

**American Foundrymen's Association,** Stevens Hotel, Chicago, Ill., week of May 4th, 1931.

◆ ◆ ◆

The **Titan Metal Manufacturing Company** is making a 60 × 200 ft. extension to their brass rod mill. The contract for the building and equipment have already been placed and the new mill should be in operation by March 1st.

◆ ◆ ◆

**Ryan, Scully & Company,** Philadelphia, manufacturers of industrial heating equipment, announce that the **Railway & Power Engineering Corporation, Ltd.,** with general offices at 171 Eastern Avenue, Toronto, will in the future exclusively manufacture and sell Ryan-Scully products in Canada.

# WROUGHT IRON

## Some Pros and Cons, and the Need for Research

### A Correlated Abstract

By H. W. Gillett *

Wrought iron is a relatively weak ferrous material. Yet its engineering applications are very often those in which it gets pretty rough usage. One might expect, on cursory thought, that stronger materials would be rapidly substituted for it. This, of course, did happen to a large extent in the days when iron had been the only ferrous material of construction, and steel first came into use.

But the replacement has never been complete, even though the cost of wrought iron is considerably above that of non-alloyed steel. Its chief users, for purposes where mechanical properties, rather than corrosion resistance, come into play, are railroads, and certainly the railroads do not very often use materials of higher cost than will serve the purpose.

In an attempt to analyze the situation into its engineering components, we have studied the recorded laboratory tests, the claims of the makers of wrought iron and the opinions, based on service data and general experience, of its users. We are left somewhat perplexed, and thoroughly convinced that this venerable material has been badly neglected from the point of view of research on engineering materials.

Foremost among the makers' claims, is, of course, corrosion resistance. The arguments stress the presence of hundreds of thousands of tiny slag filaments per square inch as vital factors in retarding corrosion, while purity and homogeneity of the metallic part of the aggregate of metal and slag are adduced as additional or alternative factors if you don't care for the slag explanation.

Discussion as to corrosion resistance has been long and heated and probably will become still more heated as the price of wrought iron goes down. The struggle among commercially pure iron, soft steel, copper-bearing steel, wrought iron and similar competing products for corrosion-resistant uses is an interesting, almost a pathetic, one.

So much effort is put on attempting to establish a real advantage of one or the other for a given service at the price at which it must be sold, on meager, and to an engineer unsatisfactory, evidence, often on the basis of non-representative accelerated tests on a few specimens or on service comparisons so beset with variables as to afford no true comparison, that the user is inclined to say "a plague on all your houses" when he tries to get at the true facts. Corrosion is affected by so many uncontrollable variables that it is now rather evident that even the comprehensive exposure tests of the American Society for Testing Materials and the soil corrosion tests of the Bureau of Standards, while they do establish some facts beyond cavil, yet leave many questions still open to argument, and indicate that still other thorough-going, impartial tests on very much larger numbers of specimens and at many locations would be required to settle matters. And when, after 15 or 20 years of such exposure tests, the results are in, each maker can claim that he has so improved his methods of manufacture that the material in the test no longer represents his present improved product!

In some types of service, a pretty good case can be made out for a useful life of wrought iron over some of the competing materials in about the same ratio as their relative costs, leading to endless discussion as to the over-all cost when cost of replacement is considered. Sometimes, in comparing almost any pair of these competing materials, even though the evidence as to longer average life of one of them is pretty strong when enough installations are considered to allow statistical treatment, some of the installations show lives no better than the best of the competing material. Unfortunately, the service variables are seldom so clearly understood that a prospective user can be sure how the two materials will show up in his own service. If he could buy a rabbit's foot or a horse-shoe with his iron or steel, and be assured that he would be lucky enough to get results equal to the best that can be shown for the one he buys, his choice would be easier.

If as much effort were put on analyzing service conditions to develop what separate factors are really concerned, as has been put on the study of accelerated corrosion tests, we might be further along from the engineering point of view. Desch's[1] comments are pertinent. He says, "I feel convinced that the bulk of the laboratory investigations, carried out with great care though they are, are of little use as a guide to the behavior of structural materials toward corrosive agents in practice. As a metallurgical chemist, I say this regretfully. Corrosion is the product of a number of different factors which we are able to estimate separately by refined laboratory experiments, by which we experience the greatest difficulty in combining to cover the conditions of practice."

If we grant that it is true that the factors can be separately evaluated in the laboratory, it is a matter for engineering research to determine the factors that actually count in service, and then to work back toward testing methods, possibly bringing in these factors in suitable proportions in a single test, but more probably learning how to use the results of a variety of tests in each of which only one factor is concerned.

A straight-forward, logical proof or disproof of the alleged effect of slag on corrosion resistance of wrought iron would be a help in understanding the situation. If slag-free ferrite exactly like that in wrought iron could be prepared, its study would be illuminating. Personally, we could readily accept the slag explanation if the slag had a honey-comb structure, and enveloped the iron. But the slag being more like a series of picket fences, one behind the other, through which corrosion should be able to wriggle like a snake, we can see only a probable delay rather than a stone-wall stoppage of corrosion due to slag.

Unsatisfactory as the situation is as to a logical explanation of the corrosion resistance alleged for wrought iron, we must admit that well authenticated cases of long service can be shown by it, and, for that matter, by some of the competing materials.

Just how much premium wrought iron or any of the competing materials is worth when material is to be bought for corrosion-resistance is a problem for higher mathematics, with most of the constants in the formula still unsettled. Continued research on corrosion problems must be carried on by the makers and users of all the competing materials, and probably will be.

There are many uses of wrought iron in which corrosion resistance is not a factor, or at least not a recognized one. Ease of fabrication, and the purely physical, rather than the chemical, properties are of importance in many applications.

The weldability of wrought iron, its good threading properties and its ability to take coatings such as galvanizing, seemed to be conceded. Indeed, there would appear to be a fruitful and almost unexplored field in the application of wrought iron as a base for enameling, as the coating should adhere well.

In the applications where static and dynamic mechanical properties are the criteria for usefulness, superiority of wrought iron is not generally conceded by the engineers of any save the railroad industry, and is certainly not so evident as to be conceded by makers of competing materials.

Some of the arguments for wrought iron in such service are sharply in conflict with research data, and may well perplex the engineer.

In Vol. 1, No. 3, of the *Wrought Iron Record*, is the following statement: "While rust-resistance is the most important advantage of wrought iron, there are others worthy of consideration. Wherever abrasion has to be taken into account, wrought iron wears better. Wherever vibration is severe, wrought iron is much less subject to 'fatigue' much less likely to become brittle with the passage of time. So engineers are turning to a reconsideration of wrought iron as a favored material for bridge building."

In the same issue is a quotation from a circular issued by the British Council of Wrought Iron Associations, which claims that

* Editorial Director

[1] C. H. Desch, Quoted in *Wrought Iron Record*, Vol. 1, No. 4, page 4.

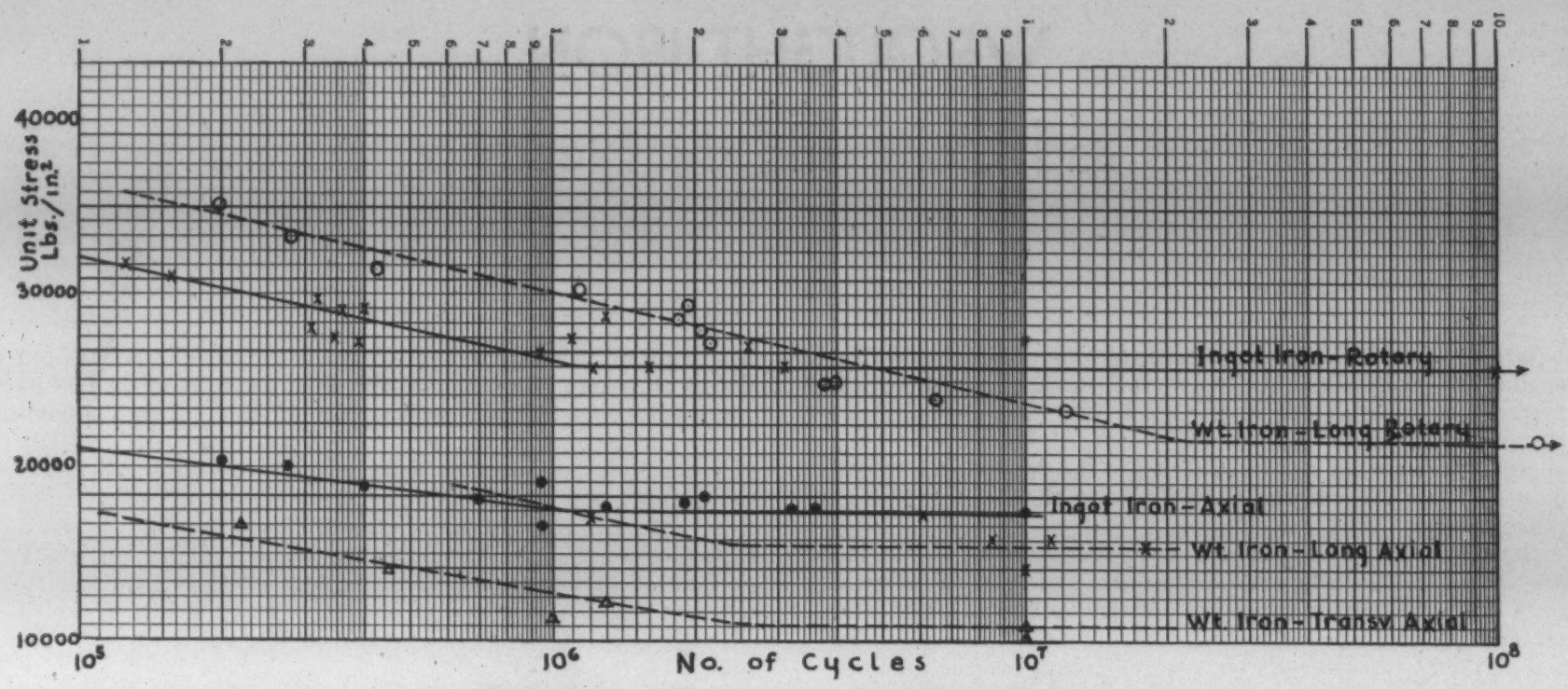


Fig. 1—Results of Moore and Jasper Investigation of Fatigue

wrought iron "will retain its strength at high temperature (up to 450° F. [232° C.]) where the strength of steel, copper, etc. has fallen off by 15%."

The quotation also states, "It has a very high fatigue strength, and is used in many instances to withstand alternating stresses. It is also eminently suitable for resisting torsional stresses."

That is, rather sweeping claims are made for resistance to abrasion to high temperatures, and to repeated stress. Several users point out though that the "wherevers" are a sort of poetic license, and should only be taken to refer to new uses analogous to those for which wrought iron is already employed, and to involve comparison with such competing materials as mild steel.

In regard to abrasion resistance, one maker of wrought iron cites the case of a pump rod, in which the rod wore down so as to leave slag particles in relief, abrasion of the rod itself then ceasing.

Similar claims for freedom from galling are made by steel makers for stainless steels carrying zirconium sulphide particles. For applications where seizure may occur, seizure may be more serious than wear resulting from abrasive particles embedded in the iron or steel. Yet, in most cases of metal to metal contact, one would wish to avoid the presence of hard non-metallic particles.

One case is cited where wrought iron tubing has replaced steel tubing in a few oil wells where the sucker rod was bearing on the tubing, and wearing it out, with much superior service reported for the wrought iron tubing. Wrought iron sucker rods are said to be working well in districts producing high sulphur oil.[2] It would be interesting to have the service factors appraised, in the instances where abrasion-resistance is thought to exist, to see how far corrosion, and the barring by abrasion of fresh metal surfaces unprotected by corrosion-products to further corrosion, may come in. We recall no work on wear-resistance of wrought iron, and the engineer considering the claims may well wish for a more thorough study of methods of wear testing, of the properties of wear-resisting alloys in general, and of wrought iron in particular. Certainly research is needed in this respect.

In respect to high temperature service, it happens that many steels are, according to the résumé of French and Tucker,[3] stronger at 450° F. (232° C.) than at ordinary temperatures, so the claim that wrought iron is superior to a steel that weakens at 450° F. (if any do) certainly needs backing up.

Trinham[4] gives a table on retention of strength at high temperatures, showing wrought iron to retain or exceed its room-temperature strength up to about 750° F., and his figures would indicate it to be actually stronger at 900° F. and above than mild steel.

[2] The Fabrication of Wrought Iron Sucker Rods. Anon. *Wrought Iron Record*, Vol. 1, No. 4, pages 21–23.

[3] H. J. French & W. A. Tucker. Available Data on the Properties of Irons and Steels at Various Temperatures. *Proceedings American Society for Testing Materials*, Vol. 24, II (1924) pages 56–87.

[4] J. S. Trinham. Progress in the Metallurgy and Utilization of Wrought Iron. Paper of Nov. 5, 1929, *Staffordshire Iron & Steel Institute* (1930) 25 pages. See also F. A. Epps & E. O. Jones. The Influence of High Temperature upon the Elastic and Tensile Properties of Wrought Iron. *Metallurgical & Chemical Engineering*, Vol. 17 (1917) pages 67–71.

A more logical argument for high temperature performance of wrought iron for service in which steel shows grain growth appears to be first the absence of pearlite, hence no structural instability due to balling up of pearlite, and second, the presence of slag filaments to prevent growth of excessively large grains of the iron. Much work has been done on high-temperature properties of steels, but extension of such research to wrought iron, even for comparative purposes, seems to have been neglected.

The abrasion resistance and high-temperature resistance applications of wrought iron are, so far, rather limited. Fatigue resistance and impact resistance, however, are concerned in many uses, and the situation there deserves much closer attention.

From the point of view of laboratory tests alone, wrought iron is about the weakest wrought ferrous material under repeated stress. In general, the endurance limit of wrought ferrous materials determined in reversed or rotary bending, is, in the absence of corrosion, about half their tensile strength. Moore[5] gives the following endurance limits in rotating beam and axial loading tests:

| Materials | Endurance Limit, lbs./in.² Rotating Beam | Axial | Tensile Strength lbs./in.² | Charpy Notched Bar ft.-lbs. | Brinell |
|---|---|---|---|---|---|
| Wrought iron longitudinal | 23,000 | 16,000 | 46,900 | 17.5 | 105 |
| Wrought iron transverse | 19,000 | 11,000 | 34,400 | 4.8 | 105 |
| Ingot iron as rolled | 26,000 | 17,000 | 42,400 | 19.3 | 69 |
| Structural steel 0.18% (as rolled) | 28,000 | .... | 61,500 | .. | ... |

Some of these results are plotted in Fig. 1.

Recent unpublished work by other investigators indicates a higher endurance limit on longitudinal bars in rotating beam tests, figures of 29,000–31,000 lbs./in.² having been obtained. These data would class wrought iron along with ingot iron as showing a higher endurance ratio than soft steels. They would also indicate that, when tested longitudinally, the slag had little effect on the endurance properties.

Of course, as we go to higher tensile strengths in steel with higher carbon, with alloying elements, or after heat-treatment, the endurance limits rise correspondingly, so that when resistance to repeated stress is sought, the usual choice would be one of the stronger materials rather than wrought iron.

The question at once arises whether the fibrous structure of wrought iron, due to the slag stringers, is desirable or undesirable under repeated stress.

Most workers on endurance consider that non-metallic inclusions in iron or steel are detrimental and indeed the urge for clean steel comes largely from the belief that dirty steel is unreliable under repeated stress.

[5] H. F. Moore & T. M. Jasper. An Investigation of the Fatigue of Metals. *University of Illinois Engineering Experiment Station, Bulletin* No. 142 (1929) pages 47, 51, 58. H. F. Moore. Manual of Endurance of Metals under Repeated Stress (1927) page 52.

Sisco[6] says, "In the work done at Wright Field, a mass of evidence has been accumulated that shows without doubt that non-metallic inclusions are responsible for, or at least accelerate, fatigue failure."

Haigh[7] made some reversed axial loading fatigue tests 15 years ago, when the necessity for carrying endurance tests to many millions of cycles was not thoroughly appreciated. His tests stopped at 3 million cycles, and the curves were still showing an appreciable slope, so that the endurance limit was not reached. His endurance figures, at 3 million cycles, were: Swedish wrought iron, annealed, 22,500 lbs./in.$^2$ Same, after being stretched 10% in a tensile test, 26,000; same after stretching and heating to 100° C. for 30 minutes, 29,000. The usual improvement due to cold-working a ferritic material is thus shown.

Haigh shows an interesting photograph of a fatigue failure in a wrought iron test bar in which the cracks started at the junction of a slag stringer and the metal. The cracks did not cross the slag. Haigh concludes that "the presence of slag is in general very undesirable" in steel subjected to alternating stress.

Moore and Kommers[8] cite Lea as tracing failures in bolts on couplings and connecting rods, to slag inclusions, and as having the opinion that it is a mistake to use wrought iron bolts in such cases.

Wrought iron is not materially handicapped in fatigue resistance by the presence of slag as long as the applied stress is longitudinal, for it is well known that longitudinal scratches on the surface have no appreciable effect on endurance, while transverse scratches seriously diminish it. Internal discontinuities act in similar fashion. In the case of torsion, the longitudinal ones have the worse effect, so the claim that wrought iron would be useful under repeated torsional stress demands thought before acceptance.

That the "grain" of wrought iron is a source of weakness when stress acts across the grain is brought out by failures of hooks, drop-stamped out of a flat bar, recorded by Wraight and Hinde.[9]

How much of the alleged suitability of wrought iron for fatigue service is due to the toughness of the material, and how much to the presence of slag, i. e., whether a pure ferrite without slag would be more or less desirable than wrought iron, is still another question. Howe[10] remarked, "Because toughness and slag both cause fiber, some be-fogged ones infer that slag causes toughness." Howe, however, points out that in wrought iron slag decreases the tendency of rupture to strike across the metal rather than shear along it. The more ready propagation of an advancing crack in a slag free ferrite than in wrought iron is also commented on by Rawdon and Epstein.[11]

The advocates of wrought iron claim that the presence of slag will stop an advancing crack, much as the drilling of a hole at the end of a crack in a cracked plate glass show window reduces the local stress from a very high value at the apex of the crack, to a much lower one due to the greater radius of the "notch" in the drilled hole.

It might be argued that even though wrought iron has a low endurance limit, it is less damaged by poor fillets, sharp shoulders or notches than other materials.

Some isolated figures given by Souther[12] would support this idea, though obtained when endurance testing methods were very crude. He compared wrought iron with a basic steel of 0.07% C 0.52% Mn, chosen to give about the same yield point and tensile strength as the wrought iron, by running both at one given stress in rotary bending. The data follows:

| | Yield Point lbs./in.$^2$ | Tensile lbs./in.$^2$ | Elong. % in 2″ | Red. Area, % | No. of Cycles to Fracture at 28,000 lbs./in.$^2$ |
|---|---|---|---|---|---|
| Wrought Iron | 37,400 | 53,000 | 24 | 35 | 17½ million, broken<br>21 million, unbroken |
| Soft Steel | 36,000 | 56,500 | 40 | 64½ | 0.8 million, broken<br>0.2 million, broken |

The radius usually used on the test bars in these early rotary beam tests was usually such as, in the light of more recent work, would give actual local stresses above those calculated.

Data from Stanton and Bairstow[13] show the following approximate figures for endurance limits in lbs./in.$^2$:

| | Fillet 3/8″ Radius | Fillet 0.062″ Radius | Square Shoulder |
|---|---|---|---|
| Bessemer Steel | 35,500 | 24,500 | 17,500 |
| Mild Steel | 29,000 | 21,000 | 16,000 |
| Wrought Iron | 24,000 | 17,500 | 14,500 |
| Swedish Iron | 21,000 | 14,000 | 11,500 |

The percentage decrease due to sharp changes of section is not materially different in the soft steels and the irons, and in absolute values, the wrought irons are the weaker.

Interesting data along this line have been presented by Gough and Murphy.[14] They studied the failure of wrought iron chains, and concluded that these failures, resulting from tensile and impact stresses, not reversed, but of course many times repeated (although they showed a brittle type of fracture resembling a fatigue fracture), were not due to repeated stress as such, but to the development on the co-acting surfaces of the links of a very thin work-hardened layer from the rubbing of one link on another. This produces a skin which is brittle and in which sharp cracks may form. When they do form, impacts produce propagation of the sharp cracks through the ductile core. Case-hardened wrought iron behaved in the same way, the core was not able to stop a crack starting in the brittle case.

When a rather sharp discontinuity was formed by hammering a cylindrical bar in a Stanton repeated impact machine with a 3/8″ diameter tup, some 200,000 or more blows being applied, and the battered specimen was then tested in a Charpy impact machine without removing the "notch" formed by hammering, the energy absorbed fell to half that of an undamaged bar, and the bar broke with a brittle fracture. But if bars so notched by hammering were given a 650° C. (1202° F.) anneal for an hour to soften the work-hardened surface at the corner of the notch, the energy absorbed was the same as on an undamaged bar, and the bars bent without fracture or sign of crack at the sharp corner, showing ductile flow. As long as the material was ductile throughout, local flow at a sharp notch evidently rounded off the apex of the notch and no crack was formed.

That the failure of an actual chain was due to shock or impact conditions was postulated when the wrought iron was tested in repeated tension on a Haigh endurance machine, and found to have an endurance limit (for axial loading from no load to tension only, no compression) of 42,000 lbs./in.$^2$, which is above the yield point, so that marked flow and moderate strain-hardening of the whole cross-section resulted. No such marked deformation is met in actual chain failures, and it was concluded that the cause of chain failures is not fatigue.

No fatigue tests are reported on material on which a brittle work-hardened skin has been produced, so it is not quite clear whether the actual failure is due to impact or to repeated stress. Either type of loading on a specimen with a crack in a brittle skin might produce a brittle fracture.

Representatives of several railroads quote approvingly the comment of Howard[15] that wrought iron retains its toughness at the root of an incipient crack, while a non-fibrous metal acts in a brittle fashion.

Several users point out that the ductility and toughness of wrought iron is of a different character than that of steel, as evidenced by more general elongation and reduction of area in the tensile test, the flow of steel in the test being more localized.

One next turns to the consideration of the ability of wrought iron to withstand a few applications of severe overstress without material damage.

Hatfield[16] tested a wrought iron (0.06 C, 0.12 Mn, 0.13 Si, 0.02 S, 0.25 P) of 51,500 lbs./in.$^2$ tensile, 31,500 yield, 29% elongation, 48% reduction of area, 44 ft.-lbs. Izod, and decided that the endurance limit would probably lie somewhere between 26,000 and 17,000 lbs./in.$^2$ He comments especially on its behavior at very high stresses. While, on account of yielding, the

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[6] F. T. Sisco. Steel Failures in Aircraft. *Transactions American Society for Steel Treating*, Vol. 15, April 1929, page 589.

[7] B. P. Haigh. The Endurance of Metals under Alternating Stresses. *Journal West of Scotland Iron & Steel Institute*, Vol. 23 (1915) pages 17–49. See also H. J. Gough. Fatigue of Metals (1926) page 191.

[8] H. F. Moore & J. G. Kommers. The Fatigue of Metals (1927) page 198.

[9] E. A. Wraight & P. Hinde. Failures of Railway Materials Dealing Chiefly with Ferrous Metals. *Government of India Publication* (1930) 61 pages. Reviewed in *Metallurgist*, July 25, 1930, page 112.

[10] H. M. Howe. Metallography of Steel and Cast Iron (1916) pages 589, 592.

[11] H. S. Rawdon & S. Epstein. The Nick-Bend Test for Wrought Iron. *Bureau of Standards Technical Paper* 252, Vol. 18 (1924–1925) pages 115–155. See page 142.

[12] H. Souther. Characteristic Results of Endurance Tests on Wrought Iron, Steel and Alloys. *Proceedings American Society for Testing Materials*, Vol. 8 (1908) pages 379–385.

[13] T. E. Stanton & L. Bairstow. The Resistance of Iron and Steel to Reversals of Direct Stress. *Proceedings Institute Civil Engineers*, Vol. CLXVI, 1906. See also H. J. Gough. The Fatigue of Metals (1926) page 82.

[14] H. J. Gough & H. J. Murphy. The Causes of Failure of Wrought Iron Chains. *Department of Scientific & Industrial Research. Engineering Research Special Report* No. 3 (1928) 167 pages. H. M. Stationery Office, London, pages 118, 138.

[15] J. E. Howard & W. P. Borland. Report of the Director of the Bureau of Safety on Balloch, N. H., Accident of Feb. 13, 1928. *Interstate Commerce Commission Report* of June 22, 1928.

[16] W. H. Hatfield. Further Notes on Automobile Steel. *Proceedings Institution of Automobile Engineers*, Vol. 15 (1921) page 465.

actual stress cannot much exceed the yield point, calculated stresses were applied that figured out to be even above the tensile strength. At such a calculated load of 57,000 lbs./in.² a rotating beam endurance specimen lasted 1400 revolutions. Hatfield says, "It appears remarkable that with really heavy loading the wrought iron resisted such rapid reversals of stress for so long."

Fig. 1 indicates that, although wrought iron has a lower endurance limit than ingot iron, for example, it may stand up longer at stresses far above the endurance limit, e. g., those causing failure in less than half a million cycles.

There seem to be no data at all on the effect of overstressing wrought iron, that is, applying to a series of specimens, say, only a tenth or a quarter as many cycles at a given high stress as would cause failure at that stress and then again testing these specimens at lower stresses to see how badly they have been damaged and how far the endurance limit has dropped. A little information along this line has been collected on various steels and non-ferrous alloys, but apparently not on wrought iron. Research along this line would certainly be of interest.

The Engineer of Materials of one large railroad with whom we have discussed this subject, says that in the old vibratory test for stay bolt materials, in which a specimen is given a large deflection, so that it fails at a few thousand cycles, i. e., is stressed far above its yield point, a comparison of an alloyed open-hearth iron with a double worked wrought iron showed the former to give longer life when a $^5/_8$" radius groove was used, but when a sharp V-groove, the same as the standard 12-pitch stay bolt thread, was tried, the wrought iron came out ahead by enough of a margin to be important. This tends to substantiate the mechanic's idea that a crack will travel faster in a more homogeneous material than it will in wrought iron.

This idea is so thoroughly accepted by this railroad that it would like to get very large diameter wrought iron forgings for axles. At present, such material cannot be obtained free from seams and the desire cannot be satisfied. If good forgings could be obtained, they would be used instead of 0.5% carbon steel. The reason is that the axles normally run tolerably warm and thermal checks can hardly be avoided. When it is necessary to design a part in which a crack may be expected to start during normal operation of the part and it must hang together between inspections, a material in which a crack would progress more slowly would be welcomed.

Reverting to the stay bolt problem, it is not only resistance to repeated stress that is important, but the stay bolts should not stretch and loosen in service. Hence, a high static yield point is required. When soft steel of, say, 50,000 lbs./in.² tensile is substituted for wrought iron of equal strength, the steel does not work out as well, since the wrought iron has the higher yield point. For maximum rigidity of bolting combined with resistance to repeated stress, nickel steels are now coming into use.

Another large railroad says, "We have no data to show that wrought iron has greater fatigue resistance than steel based on tests conducted at stresses within the elastic limits of the materials. In fatigue tests in which the metal is stressed beyond its elastic limit in accordance with the usual methods of testing stay bolt iron by railroad laboratories, we believe it is true that wrought iron is more resistant to fatigue than steel."

This is not always the case in laboratory tests, for one railroad, in the effort to both cheapen and improve its engine bolts, surveyed the various steels available, and finally selected a low carbon, slightly alloyed steel (0.10% C, 0.46% Mn, 0.25% Si, 0.38% Ni) for trial. This had, in static tests, appreciable superiority over wrought iron, and in the "vibratory" test, its life, in the laboratory, was almost double that of wrought iron. But, in service, over a period of 3 years, there was not 1% difference in the engine-miles per bolt failure, and the cost of machining and threading more than made up for the lower initial cost of the steel. The data follow:

| | Yield Pt. lbs./in.² | Tensile lbs./in.² | Elong. % in 8" | Red. area % | Vibratory Test No. Revolutions | Engine-Mi. per Bolt Failure |
|---|---|---|---|---|---|---|
| Wrought Iron | 32,500 | 49,000 | 30.5 | 49 | 65,900 | 13,460 |
| Low Ni Steel | 38,500 | 58,000 | 34.5 | 68 | 120,500 | 13,295 |

Hence, this road continues to use wrought iron, and has a rather low opinion of the "vibratory" test.

Several railroad men point out that wear in the gripping jaws of the "vibratory" machine make the indications of this test open to considerable question. Of course, such a test can by no means be considered as a modern fatigue test.

Another railroad experience may be cited. Annealed car axles of plain 0.40–0.55% carbon steel were substituted by a 0.40% C, 1% Cr, 1.7% Ni, 0.05% V steel, heat-treated to 156,000 lbs./in.². The static tensile properties were about:

| | Yield Point lbs./in.² | Tensile lbs./in.² | Elong. % in 2" | Red. Area % |
|---|---|---|---|---|
| Carbon, annealed | 40,000 | 80,000 | 22 | 35 |
| Alloy, heat-treated | 135,000 | 156,000 | 14.5 | 45.5 |

The endurance limit of the alloy steel would surely be above that of the carbon steel, and the alloy steel is far from devoid of ductility. But the first car with the alloy axles was wrecked by a broken axle on its first trip. Other axles on other cars broke faster than they could be removed from service. Replacement by the old type annealed carbon axles resulted in service without a single failure in four years up to date.

Such experiences make the railroad people chary of applying materials that laboratory tests show (or would show if they were tested) to have high endurance limits, to service in which common engineering opinion assumes that repeated stress is the chief cause of failure. Hence, the laboratory data on wrought iron does not appeal to them as giving correct indications.

The fatigue question seems to sift down to the idea that when design has to be such that anything available will actually crack in service, the rate of advance of the crack will be slower, and hence, the life longer in wrought iron than in some competing materials, as long as the service does not produce a brittle skin on the wrought iron.

Another special application is in car and locomotive piping. In this service, steel pipe is reported to break at the threads where it enters the fitting, while wrought iron stands up better. In order to resist corrosion, extra heavy wrought iron pipe is used. It is not clear whether the failures are cases of pure fatigue, of corrosion-fatigue or in fact, of impact. The fracture appears to start from the outside. The pipes show corrosion, both inside and out.

Similar piping failures are met in aircraft where vibration causes fuel and oil lines to crack. The problem is being met there by the use of flexible fittings, and by tying down the pipes solidly at many places so that no great amplitude of vibration is possible. Copper piping is used, and it is commonly accepted practice to anneal the pipe after every hundred or so hours in the air to remove any effect of cold-working that has come from vibration. From laboratory endurance tests, it would appear that this practice is quite erroneous. Cold-worked copper appears to have a little better endurance limit than annealed copper, and brass pipe should be better than copper, as far as the laboratory tests go, though the service data appear to favor copper. We are not thoroughly convinced that the aircraft practice may not be a superstition rather than based on sound engineering, for not so long ago, an attempt was made to find out on what tests or observations this practice was based, and no test reports were forthcoming, the practice apparently having been decided upon on the basis of verbal reports and opinions.

If we give full credence to the apparent testimony of service in behalf of wrought iron piping versus steel, and of annealed copper versus hard drawn copper or brass, we have this testimony diametrically opposed to the findings of all laboratory endurance test results.

In other fields, endurance data are being found of value in engineering design. To what is due the apparent failure of laboratory and service tests to agree?

An interesting example of laboratory testing of wrought iron which did not give the expected result is found in the last report of the A.S.T.M. Committee on Wrought Iron.[17]

In these tests, wrought irons with phosphorus ranging from 0.06–0.45% were given tensile tests, and also subjected to a "vibratory" test on the Olsen vibratory machine in which a 9" specimen is given a $^3/_{32}$" oscillation. The load is figured at 5500 lbs./in.², but, due to local stresses in the groove of the bar, is of course actually very much higher, as failure ensued in 6000 to 40,000 cycles.

It was thoroughly to be expected from the work of Rawdon and

[17] J. H. Higgins. Investigation of the Effect of Phosphorus in Wrought Iron. Appendix II to *Report of A.S.T.M. Committee A2 on Wrought Iron Preprint* No. 10, for June 1930 Meeting, 14 pages.

Epstein[18] that the higher the phosphorus the higher would be the tensile strength and the lower the ductility. It was likewise to be expected that the higher the tensile strength, the higher would be the resistance to vibratory stresses, at least in any regular endurance test.

In fact, McIntosh and Cockrell[19] made a direct study of the effect of phosphorus on low carbon steel, and found that increase in phosphorus did not decrease, but rather increased the endurance limit.

That similar results were found in the "vibratory" tests of wrought iron seem to surprise and shock the A.S.T.M. Committee which states, "The vibratory tests also show an increase in vibrations before failure as the phosphorus increases. This is at variance with general expectation and opinion and may necessitate additional tests for clarification." They advance the theory that in service the iron has "rest" or "recovery" periods while the tests were carried on continuously to failure. Some maintain that wrought iron has particular merit in ability to "recover."

One investigation has been recorded which might seem to justify the assumption that wrought iron "recovers." Bernhard[20] made some tests on riveted spans from an old wrought iron footbridge. The natural frequency of the bridge was determined, and repeated loading applied till members began to fail at rivet holes in gusset plates. The natural frequency changed as the nature of the structure changed due to the failures. After a ten hour rest, the natural frequency was found to have altered, and it is postulated that "such intervals must have an appreciable effect in lengthening the life of the bridge."

Such a test is a test of a structure and of a structure that was cracking and loosening. To assume that the change in frequency is due to a recovery in the material seems unwarranted.

Particular attention has been given by students of fatigue to the question of the effect of rest periods. The phrase "fatigue" would, by analogy with muscular fatigue, appear to connote the existence of recovery periods. However, all the evidence goes to show that a "fatigue" failure is a progressive failure under repeated stress, that the damage done by over-stress is irreparable, and that neither rest-periods nor the frequency of the applied stress, at least up to around 5000 cycles per minute, (unless corrosion comes in also) affect the endurance. At stresses above the endurance limit, failure ensues after the number of cycles called for by the stress-cycles diagram, without any influence of rest periods. This is so thoroughly established by careful tests made for the purpose on many kinds of alloys that any claim that wrought iron deviates from the general rule should be based on specific evidence. On the other hand, wrought iron has not been included in any tests on the effect of rest periods that we can recall.

Trinham[4] gives hysteresis loops of wrought iron and mild steel which do tend to show that wrought iron recovers from overstrain much more rapidly; also citing Tudsberry and Gibbs[21] to the effect that a 100 year old wrought iron bridge which had been subjected to wind-vibration, and had been stressed above its original elastic limit, when dismantled and tested, showed that the elastic and endurance limits have not been appreciably affected by overstrain caused by vibration.

Howard[15] shows that the increased strength obtained by cold-working in a tensile test, was retained for 46 years. He even cites a bar of wrought iron stressed above its elastic limit of 32,700 lbs. to 35,000 lbs/ in.$^2$, which, after 8 days rest then showed an elastic limit of 40,000 lbs./in.$^2$, which sounds odd, but is in line with the data previously cited from Haigh.[7]

The ability of wrought iron to absorb energy needs to be brought out more clearly than has been done. If it is an exception to the rule that rest periods do not influence the progress of a fatigue failure, it would clarify our concepts of fatigue to have this demonstrated.

Oddly enough, the A.S.T.M. Committee made no impact tests in connection with their repeated stress tests. Rawdon and Epstein showed that Izod impact values on two lots of wrought iron of 0.12–0.14% P ranged from 41 to 63, averaging 44 ft.-lbs. on one lot, and averaging 58 on another, while in a lot with 0.29% P the range was 6½ to 27 ft.-lbs., averaging 17. Similar results were obtained on repeated impact tests.

These Izod values were on longitudinal specimens. Petrenko[22] found 58½ ft.-lbs. Izod for longitudinal specimens of good wrought iron, but only 39½ for transverse specimens.

Ingot iron was much more uniform, 58½ ft.-lbs. longitudinal, 53 transverse; boiler plate showed 16½ longitudinal, 15 transverse.

One suspects that the utility of wrought iron must be due to ability to resist impact rather than repeated stress. But i s a rather variable material under impact due to its non-homogeneity, and it falls below relatively slag-free ferritic materials, such as ingot iron, in impact on transverse specimens. Care should be, and usually is, taken in designing wrought iron parts, to avoid transverse stress as far as is practical.

That impact tests do not tell the whole story is pointed out by one railroad which supplies the following figures on different kinds of wrought iron.

How, they ask, could one appraise the service value from these data? None of the specimens were broken clear through so that the energy absorbed went partly into the fracture, as far as it extended, the rest into bending the bar. In most steels giving Izod figures of this magnitude, the bar is broken, and not bent.

Even when the bar is completely broken, Moser[23] finds that the volume of metal strained in the test, and the velocity of strain propagation must be considered in evaluating the properties of the metal. Moser says, "A railway axle is required to stand up under sudden, rapid shocks in ordinary use or on sudden violent impact against an obstacle; it should, therefore, at the worst, be only deformed. This would, therefore, be a question of the behavior of the material against high striking velocity, and therefore materials which can deform rapidly are required."

Current studies of the impact test undertaken to determine the ability of metals to propagate strain, and distribute stress under impact, do not seem to be including wrought iron.

McKnight[24] comments on the trend in forgings for railway use. Originally wrought iron was used, then carbon steels, then alloy steels, till the practical limit of tensile strength for normalized

**Qualities and Physical Characteristics of the Test Bars**

| Kind of Iron | Test No. | Original Size, inches | Tensile Strength lbs./in.$^2$ | Yield Point lbs./in.$^2$ | Red. of Area, % | Elong., % | Izod Values, ft.-lbs. Longitudinal. Ave. of 3 Tests. "A" Notch at Right Angles to Flat Plane of Piling, "B" Notch at 90° to "A" | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | *A* | *B* |
| Staybolt | 1 | 1 Rd. | 50,210 | 37,290 | 52.1 | 33.5 | 45 | 44 |
| Enginebolt | 2 | 1 Rd. | 49,230 | 38,340 | 49.8 | 31.0 | 41½ | 42 |
| A.S.T.M. 84–27–C | 3 | 1 Rd. | 49,880 | 36,500 | 51.7 | 31.0 | 44½ | 53 |
| Busheled Iron | 4 | 1 Rd. | 51,540 | 40,880 | 57.4 | 32.5 | 51½ | 56 |
| Busheled Iron | 5 | 1 Sq. | 49,450 | 37,440 | 55.7 | 34.0 | 51½ | 65 |
| Busheled Iron | 6 | 2 × ½ Flat | 48,150 | 37,370 | 55.0 | 35.0 | 58½ | 58½ |
| Common Iron | 7 | 1 Rd. | 48,570 | 33,100 | 58.2 | 31.0 | 63½ | 70 |
| Common Iron | 8 | 1 Sq. | 48,240 | 32,400 | 61.2 | 32.0 | 62½ | 71 |
| Common Iron | 10 | 2 × ½ Flat | 48,710 | 32,590 | 42.1 | 28.0 | 43 | 51 |

[18] H. S. Rawdon & S. Epstein. Observations on Phosphorus in Wrought Iron Made by Different Puddling Processes. *Year Book, American Iron & Steel Institute*, Vol. 16 (1926) pages 117–148.

[19] F. F. McIntosh & W. L. Cockrell. The Effect of Phosphorus on the Resistance of Low-Carbon Steel to Repeated Alternating Stress. *Carnegie Institute of Technology Mining and Metallurgical Investigations, Bulletin* No. 25 (1925) 33 pages.

[20] R. Bernhard. Endurance Tests on Riveted and Welded Bridges. *Metallurgist*, Feb. 1930, pages 23–24, Abstract from *Zeitschrift Verein deutscher Ingenieure*, Vol. 73, Nov. 23, 1929, pages 1675–1680.

[21] H. T. Tudsberry & H. R. Gibbs. An Account of an Examination of the Menai Suspension Bridge. *Proceedings Institution of Civil Engineers*, Vol. 217 (1924); *Engineering*, Vol. 117 (1924) pages 23–24.

[22] S. N. Petrenko. Comparative Slow Bend and Impact Notched Bar Tests on Some Metals. *Bureau of Standards Technical Paper* No. 289 (1925).

[23] M. Moser. A New Method of Interpreting Notched Bar Impact Results. *Transactions American Society for Steel Treating*, Vol. 7 (1925) pages 297–320. See also F. Fettweiss. Die Kerbschlagprobe. Entwicklung und Kritik. *Archiv für Eisenhüttenwesen*, Vol. 2 (1929) pages 625–672 (contains 700 references).

[24] C. McKnight. Recent Developments in Nickel Iron and Steel. Preprint for May 1930 Meeting, *American Iron & Steel Institute*, 17 pages.

forgings was reached, say, 90,000 lbs./in.$^2$ or more, but with Izod impact values of only 20 ft.-lbs. The present trend is to lower the carbon and add nickel, with a slight loss of tensile strength and endurance limit, but an increase in Izod to 50 ft.-lbs.

This is not what one would be led to by endurance tests alone, as they would indicate that tensile strength was the chief aim, since endurance follows along with tensile strength.

There is plenty of evidence from practice, especially spring practice, that high endurance limits on perfectly filleted and polished specimens, with low impact resistance, are not as good for actual service as good endurance properties plus a high toughness, and resistance to notch propagation. This is well recognized in the case of rather brittle materials, but is often lost sight of when comparing materials which would all normally be considered tough.

It is well known that the simple endurance test places a premium on strength and does not show up brittleness. A balance must be struck between endurance limit and impact strength if we are correctly to appraise the service value of a material. We have previously discussed this in reference to the problem of notch propagation.[25] In the case of wrought iron, one may question the quantitative value of the usual impact test, and we are again at sea in comparison with steel.

We sent a draft of this abstract containing the citations of laboratory tests on endurance of wrought iron to a number of the railroad men on the wrought iron committee of the A.S.T.M. This brought out a surprisingly active defense of wrought iron for resistance to fatigue, and several comments to the effect that the idea that the endurance limit goes up with the tensile strength was entirely academic, and not borne out in practice.

Professor Moore has often stated that there are many types of failures of metals, and that judgment should not be passed on the basis of the endurance test alone. The true endurance test tells the *stress* below which the metal will not fail. It does not tell the ability of the metal to withstand damage by occasional overloads above that stress.

If wrought iron deserves the praises of its makers and users, based on service observations, its value ought to be demonstrable by tests, in which known and reproducible stresses are used.

In correspondence on the subject of this abstract, the vice-president in charge of sales of one firm of wrought iron producers says, "As a manufacturer of iron, the question of the qualities and attributes of that metal have been the subject of very close study and research throughout a great many years, and we have determined, to such an extent that I am able to be positive in this statement, that nothing for or against the general claims of the manufacturers may be proven by laboratory tests." Several railroad men echo this in softer tones. Of course, in this day and age, no one can laugh off the results of laboratory tests by saying that they are just laboratory tests. The laboratory test tells what happens under the conditions of the test. If our corrosion, impact and endurance testing methods do not lead to sound conclusions in the case of wrought iron, those methods need re-examination, because the testing engineer cannot laugh off the results of service either. If the test data correctly appraise the fundamental properties of the material, then the engineer must be erring in his appraisal of the sort of stresses that cause failure. What is needed, as much as further study of test methods, is a careful appraisal of service conditions to tell just what those conditions are. If the laboratory tests are not chosen to represent those conditions, they will not give the answer the engineer needs.

Facts can be gathered both from service data and from laboratory tests. When both are above suspicion, they agree, or are at least reconcilable. When they do not appear reconcilable, as in this case, it is necessary for both groups, the wrought iron producers and the fatigue and other testing experts, to give attention to the situation.

In the past 25 years, wrought iron has been included in very few metallurgical or engineering investigations of the properties of materials of construction. Some of the wrought iron people point out that in university instruction, so much time and stress is put on the carbon and alloy steels in comparison to a few hours on wrought iron, that consequently the student (the raw material from which engineers of tests, superintendents, etc. is made nowadays) is prone to overlook the virtues of wrought iron and that only the old-timers fully recognize them.

We may add that professors take material for their courses and lectures from the publications before scientific societies and in scientific journals, in the effort to keep up to date. So few papers are published on wrought iron that they might be excused for overlooking it. Papers on the new mechanical puddling processes have recently appeared, and every up to date professor tells his students something about those processes. But scientific publications dealing with the engineering properties of wrought iron compared to other materials are very scarce, and will continue to be until more research produces data that speak in the language of the modern engineer. One can hardly expect the universities to take up research on a material whose makers do not themselves publish a constant flow of research results.

And is it not peculiar that the makers of a material, advertised and advocated for both corrosion-resistance and fatigue-resistance, have never published a single test on corrosion-fatigue? The remarkably deleterious effect of combined corrosion and repeated stress was forcibly brought out by McAdam more than four years ago, and every metallurgist is now familiar with the effect. With all the research effort that has been put on corrosion-fatigue, and the large amount of information available on many ferrous and non-ferrous alloys, there seems not to have been a single corrosion-fatigue test of wrought iron. Surely there is need for more research on wrought iron.

The users feel that way too. A prominent railway engineer of tests writes us: "Based on an expereince of about 25 years in the testing of wrought iron, its methods of manufacture and comparisons with other materials such as are obtained under general service conditions, I frankly admit of belief in the generally expressed merits attributed to wrought iron. At the same time, I believe there is a real need for additional research work which will establish the material in its proper perspective with respect to the newer and competing materials.

"The expressed superiority of wrought iron over certain other wrought ferrous materials for specific purposes is based on a rather impressive background of service results but the advances made in the steel industry in the development of steels which appear to possess properties superior to those of wrought iron and which are submitted to the trade in the direct competition with wrought iron make it not only desirable but necessary that definite data be developed to clarify the situation."

[25] The Need for Information on Notch Propagation. *Metals & Alloys*, Vol. 1, Sept. 1929, pages 114–116.

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## Weston Fellowship in Electrochemistry

The fellowship ($1000) is open to candidates who have completed an undergraduate course in some college, university or technical institution, and have received a degree of such institution. The candidates must possess marked capacity in carrying out research in electrochemistry.

The candidate must be under the age of thirty years at the time of the award of the fellowship.

The award will be made without distinction on account of sex, citizenship, race or residence. The award will be made for a term of one year, but the Board of Directors of the Electrochemical Society shall have the option in its discretion of continuing the award to the same fellow.

Applications for the fellowship for the academic year October 1, 1931 to June 1, 1932, must be received by the secretary of the Society *before March 1, 1931*. Application forms are obtainable from the secretary.

The successful candidate may carry out the research in electrochemistry at any institution of learning approved of by the Board of Directors of the Society.

For further details apply to Colin G. Fink, Secretary, The Electrochemical Society, Columbia University, New York City.

## Reduction in Magnesium Metal Prices

In 1915 the average price for magnesium was $5.00 per pound. Early in 1930 prices ranged from $1.00 to 80 cents per pound. A new price just announced is 48 cents per pound in 100 pound lots or more.

The consistent decrease in magnesium metal prices due to the constant developments made by the Dow Chemical Company has caused an increase in consumption. In 1921 total consumption in this country amounted to 48,000 pounds and in 1929 over 900,000 pounds. The former high cost of magnesium has been largely responsible for its limited use, but it is predicted that with the present low prices, consumption will be greatly increased and magnesium will be used more and more where light weight is sought.

The use of magnesium metal is particularly advantageous in any industry where light weight combined with a high degree of strength and stiffness are essential factors.

# STAINLESS STEELS

## Their Production and Properties*

By Eduard Houdremont

Critical Abstract by V. V. Kendall

CONSIDERING the present lively interest in chromium and nickel-chromium steels, this review of the subject by Houdremont is of particular interest. He divides these corrosion- and heat-resisting steels from a structural standpoint into three groups, martensitic, ferritic and austenitic and then discusses the properties of the several groups from the production standpoint. Table 1 gives the important industrial steels arranged structurally. This arrangement results from the influence of chromium and nickel upon the transformation of the iron. Chromium lowers the $A_4$ point and raises the $A_3$ so that at a definite chromium content (15%) $\gamma$-iron no longer appears. Since satisfactory corrosion resistance requires a chromium content of over 13% and, for acid resistance, 15% the usual stainless steels would to a large extent fall within the range of the purely ferritic group. However, the effect of carbon in extending the region of the $\gamma$-iron-chromium solid solution results in the production of the most diverse martensitic chromium steels with a chromium content up to 25%, the properties of which can be most extensively altered by heat treatment. Also by quenching from high temperatures, martensitic chromium steels of a higher carbon content can be produced in the austenitic condition. Such steels differ from the austenitic chromium-nickel steels in that they are relatively brittle due to the remains of carbide in the grain boundaries and possess a larger grain size. The effect of nickel on chromium steels is to lower the temperature of the $\gamma \rightarrow \alpha$ transformation, finally to below room temperature, so that these steels always remain austenitic even upon heating and do not become martensitic as is the case with pure chromium steels. See the work of Bain and Griffith (*American Institute of Mining & Metallurgical Engineers*, Vol. 75 (1927) pages 166-213).

The production of corrosion-resistant steels is accomplished chiefly in the electric furnace and partly in the open-hearth furnace. Both the basic and the acid open-hearth furnace can be used. By using pure charges, no special difficulty is encountered. Nickel is generally added early to prevent heat loss at the conclusion of melting and the ferro-chromium is finally added after the melt has been killed with manganese and some silicon to prevent chromium losses. If high-chromium scrap is used in large amounts (50% or more of the charge) considerable loss of chromium will result but a portion of this can be recovered from the slag by reduction with 90% ferrosilicon. One other method using chromium ore can be used for the production of chromium steel. In this method the chromium ore is mixed with reducing agents such as high-percentage ferrosilicon and is charged into the liquid steel bath. The chromium ore is reduced by the silicon. This method has the disadvantage that exceedingly large quantities of slag must be overcome, the furnace lining is severely attacked, it is difficult to raise the chromium content of the steel over 13% and the melts produced are high in oxides and inclusions.

The electric furnace is especially suitable for the production of stainless steels, both arc and induction furnaces as well as high-frequency and low-frequency furnaces producing equally good results. Either a liquid charge from the open hearth furnace or a solid charge can be used. Solid high-percentage chromium steel scrap is generally charged only in the electric furnace in order to avoid large chromium losses. The basic arc furnace has the advantage, in the production of high-chromium steels, of reducing lime slags whereby reduction occurs automatically and more easily than in the induction furnace. On the other hand in the arc furnace there is a tendency toward carburization while in the induction furnace alloys of very low carbon content can be easily produced. Special consideration should be given to nitrogen absorption in high chromium steels due to the strong chemical affinity between chromium and nitrogen. By preheating the ferrochromium, the nitrogen absorption can be limited to from 0.014 to 0.2 %.

In premelting and remelting in the open hearth furnace especially in nickel-chromium steels care must be taken that the melt does not take up hydrogen through too early killing, as a nickel-chrome steel saturated with hydrogen gives up its gas only with very great difficulty and in teeming produces a porous casting.

In casting and in the subsequent treatment the individual groups of the martensitic, austenitic and ferritic stainless steels differ from one another. They have in common only those phenomena that are associated with too hot and too rapid casting and which are already sufficiently known.

The martensitic chromium and chromium nickel steels with 13 to 15% chromium correspond in their behavior to other high-alloy, air-hardening steels. With very low carbon content and insufficient reduction, they tend toward intercrystalline ruptures with too rapid and too hot casting and with too rapid cooling after casting, they tend to crack

* Original in *Stahl und Eisen*, Vol. 50, Oct. 30, 1930, pages 1517–1528.

**Table 1—Composition of Most Generally Used Chromium and Chromium-Nickel Steels**

| Structure | % C | % Si | % Mn | % Cr | % Ni | % W | % Mo | % Cu |
|---|---|---|---|---|---|---|---|---|
| Martensitic | 0.15–0.20 | 0.40–0.70 | 0.40 | 14–14.5 | 1.5–2.0 | ..... | ..... | .... |
| | 0.16–0.22 | 0.50–1.00 | 0.40–0.60 | 14–14.5 | 0.50–0.70 | ..... | ..... | .... |
| | 0.32–0.40 | 0.10–0.20 | 0.20–0.30 | 13–14.5 | 0.40–0.50 | ..... | ..... | .... |
| | 0.80–0.90 | 0.10–0.20 | 0.20–0.30 | 16–16.5 | ..... | 0.80–1.0 | ..... | .... |
| Semi-ferritic | 0.12 | 0.30–0.50 | 0.30–0.40 | 14.5–15.5 | (1.0–2.0) | ..... | ..... | .... |
| | 0.12 | 0.30–0.50 | 0.30–0.40 | 17 –18 | (1.0–2.0) | ..... | ..... | .... |
| Ferritic | 0.30–0.45 | 0.25–0.45 | 0.30–0.50 | 24–26 | ..... | ..... | ..... | .... |
| | 0.20–0.40 | 0.25–0.45 | 0.30–0.50 | 30–32 | ..... | ..... | ..... | .... |
| Austenitic | 0.15 | 0.30–0.60 | 0.30–0.40 | 17.5–18 | 8.5–9.5 | ..... | ..... | .... |
| | 0.15 | 0.30–0.50 | 0.30–0.40 | 16.7–17.5 | 9.5–10 | ..... | 2.5–4.5 | .... |
| | 0.15 | 0.30–0.50 | 0.30–0.40 | 17.5–18 | 8.5–9.5 | ..... | ..... | 3 |
| | 0.15 | 0.30–0.50 | 0.30–0.40 | 12 | 12 | ..... | ..... | .... |
| | 0.30–0.40 | 0.30–0.60 | 0.50–0.70 | 17.5–18 | 8.5–9.5 | ..... | ..... | .... |
| | 0.15–0.30 | 2.4 –2.7 | 0.50–0.70 | 24–26 | 19–21 | ..... | ..... | .... |
| | 0.30–0.40 | to 1.0 | 0.40–0.60 | 10–12 | 37–39 | ..... | ..... | .... |
| | 0.15 | 0.25–0.45 | 0.60–0.80 | 15–17 | 56–60 | ..... | ..... | .... |
| | 0.12 | 0.80–1.0 | 0.60–0.80 | 18–20 | 78 | ..... | ..... | .... |
| | 0.45–0.55 | 0.80–1.0 | 0.70–0.80 | 15–15.7 | 13–13.5 | 2.0 –2.5 | ..... | .... |

in the skin. The transcrystallized zone, as in all steels, is variously developed and well-pronounced depending upon the casting temperature and the velocity. In consequence of the appearance of the $A_3$ point transformation in these steels, it is possible through heat treatment, to alter the structure and accordingly the mechanical behavior of the steel in the casting stage.

The purely ferritic 30% chromium steels and also the semi-ferritic 18% chromium steels, show a very slight tendency toward transcrystallization, amounting only to a few millimeters and to from one-third to one-fourth of the transcrystallized zone of the martensitic group. The martensitic steels generally pass immediately from the liquid state into the austenitic condition which possesses a tendency toward transcrystallization. The 18% chromium steels with semi-ferritic and semi-martensitic structure show an especially fine crystal grain. This is also true of the ferritic 30% chromium steels. The purely ferritic steels are in themselves insensitive to the cooling conditions after casting. The very poorly developed transcrystallized zone, however, tends to shrink during forging. Intercrystalline ruptures have not yet been observed in these types of pure y austenitic steels. Grain size is considerably affected by casting temperature. No grain refinement can be attained through the heat treatment of cast ferritic and austenitic stainless steels. By heating to high temperatures with subsequent cooling, however, carbides at the grain boundaries and traces of intermediate substances can be brought into solution and the mechanical properties correspondingly improved.

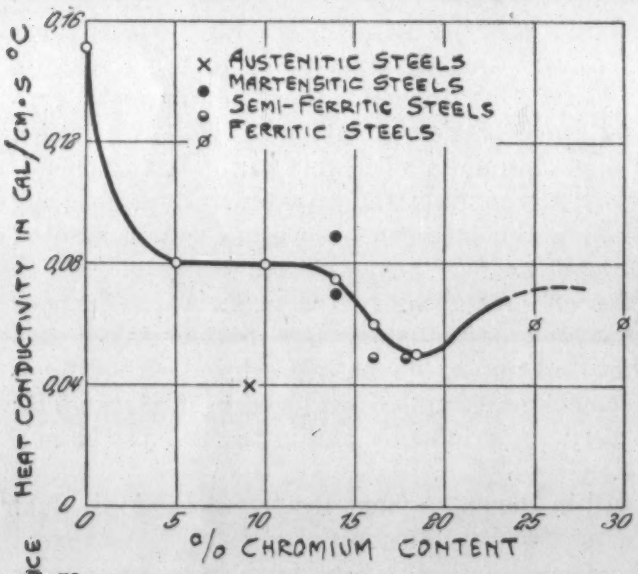


Fig. 1—The Heat Conductivity in Relation to the Chromium Content (*Stäblein*) and the Corresponding Values of the Different Stainless Steel Alloys

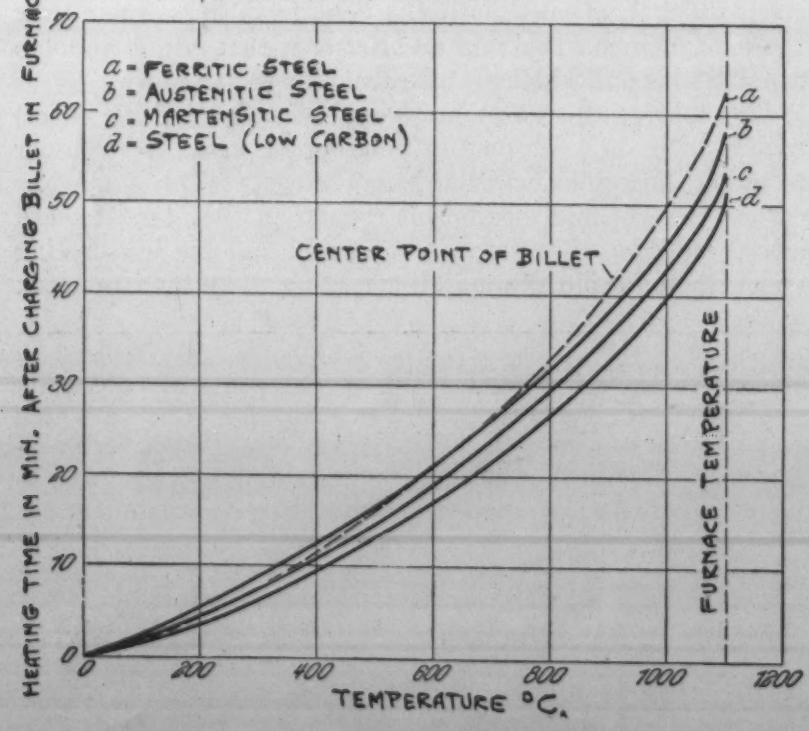


Fig. 2—Heating Time of Billets, of the Same Dimensions, of Different Steel Alloys. Heat Conductivity for a Temperature Range of 500 to 550° C.: Ingot Iron 0.11 cal./° C. cm· s; Martensitic Steel 0.09 cal./° C.·cm·s; Ferritic Steel 0.06 cal./° C.·cm·s; Austenitic Steel 0.04 cal./° C.·cm·s

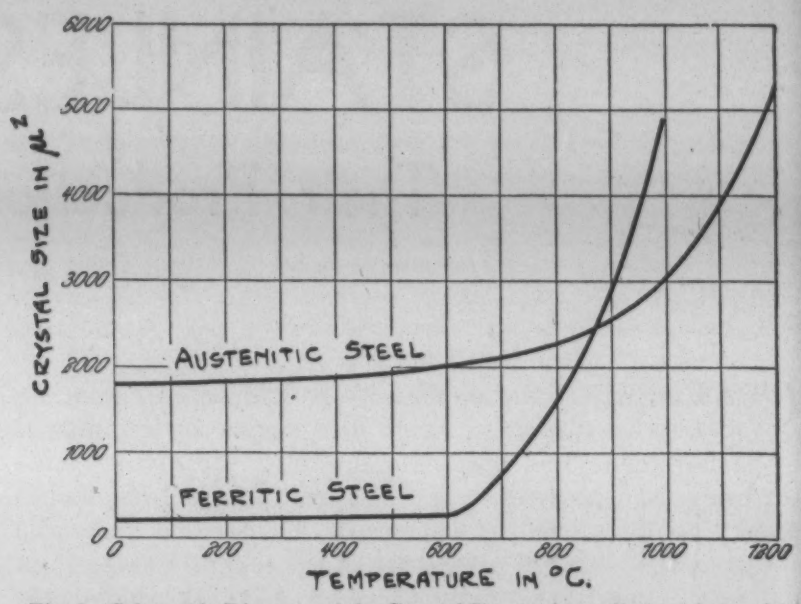


Fig. 3—Schematic Diagram of the Crystal Size on Annealing an Austenitic and Ferritic Steel

Rolling and forging in all stainless steels requires heating to over 1100° C. The heat conductivity (Fig. 1) and the time required for thorough heating (Fig. 2) determine the rapidity and duration of the heating.

Since the recrystallization temperature of the austenitic steels lies at about 100 to 400° C. higher than that of the martensitic and ferritic steels, at a rolling temperature below 1000 to 1050° C. there occurs a strengthening of the steels in the roll itself during the shaping while the martensitic and especially the ferritic steels spontaneously recrystallize during the rolling, even at high rolling velocities. Furthermore, the ferritic steels incline toward greater grain coarsening at higher temperatures, as shown in Fig. 3.

It is evident that rolls calibrated for rolling mild steel cannot be used for rolling the stainless steels. A comparison of the spreading properties is given in Fig. 4. Fundamentally all stainless steels can be cold worked but the energy required in cold working the austenitic steels is much greater than the ferritic and martensitic steels which differ little from iron in this respect.

The heat treatment of the stainless steels is of particular importance. The martensitic group are all air-hardening and must be carefully cooled after hot rolling to avoid cracks. By annealing above the $A_3$ point all desired refinements and physical properties can be attained as well as the removal of small defects from cold and hot working. Fig. 5 shows the effect of heat treatment on these steels. They can be made to vary in hardness from 170 to 650 Brinell units. Their corrosion resistance is highest in the hardened condition.

The semi-ferritic and ferritic stainless chromium steels behave essentially differently. The semi-ferritic steels with 14 to 25 % chromium and low carbon content always contain ferrite which undergoes no transformation up to heat treatment temperatures of 1400° C. The remaining part of the structure, by quenching from variously high temperatures, can be made martensitic, austenitic or deltaic (ferritic). The ferritic portion, accordingly, can be influenced by any heat treatment after working. The ferritic constituent once it has become coarse grained through too hot rolling as well as critical cold working with critical annealing, can only be refined through renewed deformation. An exact knowledge of the crystallization and recrystallization conditions is a prerequisite for the successful working of these steels.

The purely austenitic chromium nickel steels are the most simple in their heat treatment. In the hot rolled condition they contain carbides in addition to austenite which affects the acid resistance of this alloy. By quenching from temperatures of 1100° C. or above, the carbides go into solution and a purely austenitic structure is obtained. The austenitic alloy steels possess, as does austenite in ordinary mild steel, a lesser recrystallization capacity. As a result, crystallization and recrystallization troubles in welding very seldom occur.

The use of martensitic steels for the manufacture of large structures, particularly chemical apparatus due to their comparatively low acid resistance, have been slight. These steels can be riveted as well as welded, the welded seam being of the same material. However, annealing must be done after welding to remove the hardening stress.

Riveting with rivets of the same material can be done cold or hot. Riveting cold can occur only in the entirely soft carbon-low martensitic steels with rivets of the same steel. Because of the slight cold workability of these steels, there exists the danger of stress cracks in the rivet heads. In riveting cold, therefore, austenitic steel should be used. Riveting hot is best done at 600 to 700° C., i.e., below $A_3$, so that no air hardening can occur and subsequent annealing can be avoided. However, such hot rivetings are generally somewhat loose after cooling. Remains of roll scale also lead to corrosion. The ferritic steels can be welded with themselves, although, because of their pronounced crystallization tendency, they very easily become coarse grained in and alongside the weld seam. The question of welding with the martensitic and the ferritic steels, therefore, still remains to be solved.

The austenitic chromium nickel steels have thus far found the widest application in the chemical industry. Abundant experiences are available as to the possibility of manufacturing large chemical apparatus with complicated pipe systems, such as condensation towers, etc. To insure corrosion resistance, all welded structures are subsequently heat treated. The shrinkage after such heat treatment results in changing the dimensions. The problem, therefore, becomes that of investigating the physical and chemical properties of the weld as made without subsequent heat treatment. From the heat treating standpoint the recent work of Strauss, Schottky and

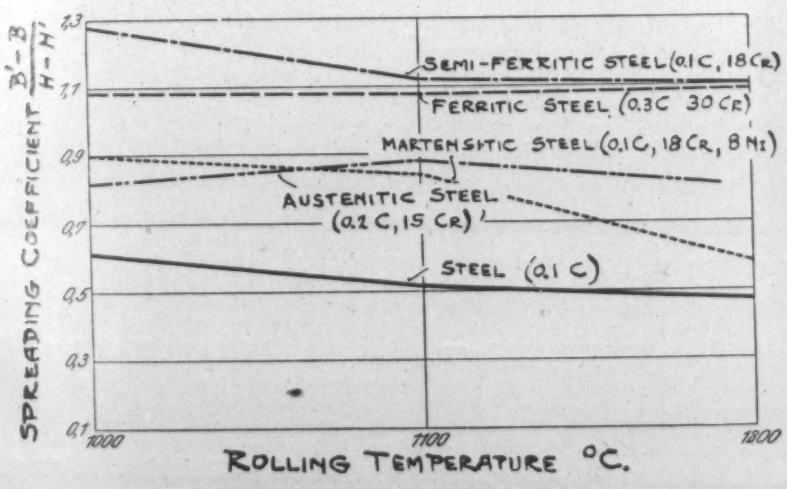


Fig. 4—Change in the Spreading Coefficient with the Alloy on Rolling Rectangular Ingots 50 mm. on a Side to Plates 24 mm. Thick

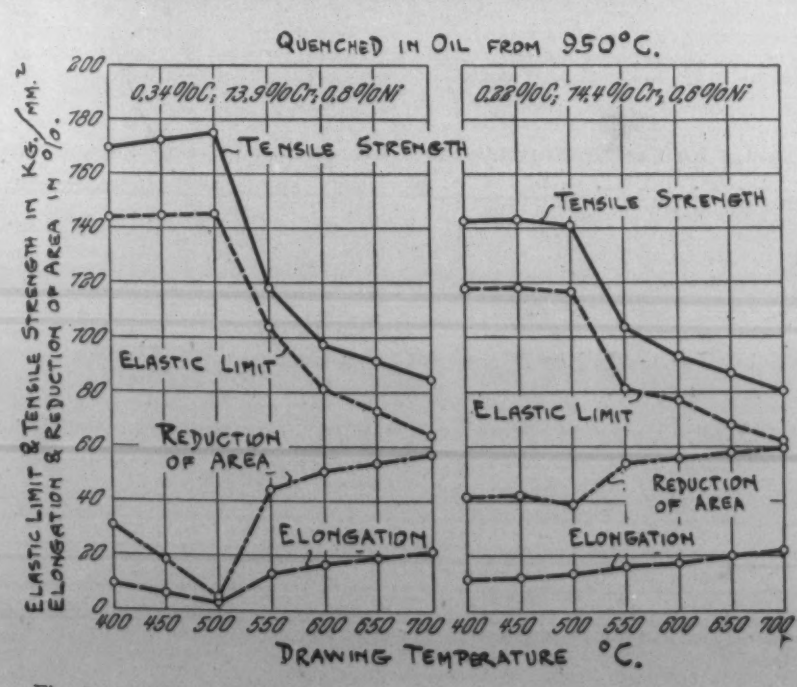


Fig. 5—Influence of the Carbon Content on the Physical Properties of a Heat Treated Chromium Steel

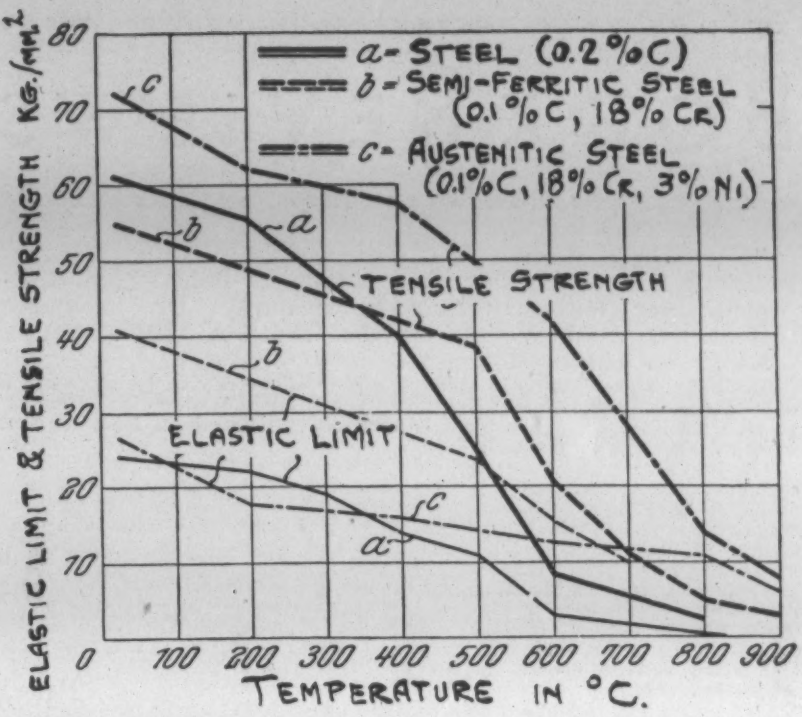
a- STEEL (0.2%C)
b- SEMI-FERRITIC STEEL (0.1%C, 18% Cr)
c- AUSTENITIC STEEL (0.1%C, 18% Cr, 3% Ni)
TENSILE STRENGTH
ELASTIC LIMIT
ELASTIC LIMIT & TENSILE STRENGTH KG./MM.²
TEMPERATURE IN °C.

Fig. 6—Change in Physical Properties of Different Chromium and Chromium Nickel Steels with Temperature

Hinnüber (*Zeitschrift für anorganische und allgemeine Chemie*, Vol. 188 (1930) pages 309-324; translated in *Metals & Alloys*, Vol. 1, Oct. 1930, pages 785-787) is of particular interest. This is quoted very fully but will not be repeated here. Intercrystalline corrosion results from the separation of carbides in heat treating and can even be produced by the short heating in welding. From a riveting standpoint the difficulties are even greater. Heat treating after riveting causes a loosening of the rivets. Riveting hot will also cause intercrystalline corrosion. Riveting cold will not produce tight seams. The problem was, therefore, attacked from the angle of altering the structure up to 600 to 700°. This resulted in an austenitic material that would weld without difficulty and that did not show preferential corrosion of the weld or intercyrstalline corrosion. It is regretable that no information as to the alloying material used or data on its exact effect on the structure is given.

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**J. Bishop & Company Platinum Works** of Malvern, Pa., and **Johnson Matthey & Company, Inc.**, 14 West 47th Street, New York City, have formed a connection whereby the latter house together with their parent company Johnson Matthey & Company Ltd. of London, England have acquired an interest in J. Bishop & Company Platinum Works.

Under this arrangement J. Bishop & Company Platinum Works will continue to operate with the same management, manufacturing platinum for technical and industrial uses, tantalum and stainless steel tubing and will add to their range of products, several new lines introduced by Johnson Matthey & Company, Ltd.

Immediate expansion of J. Bishop & Company's plant is planned, including additional laboratory facilities for electrical and metallurgical research and development.

This affiliation brings together the two oldest platinum refining and manufacturing companies in their respective countries. Johnson Matthey & Company, Ltd., was founded in London, England over a century ago, while J. Bishop & Company Platinum Works was founded at Philadelphia in 1842. Johnson Matthey & Co., Inc., has been the American representative of Johnson Matthey & Company, Ltd. since 1920.

*Heard on a Fifth Avenue bus—*
"What's that shiny stuff on the Chrysler Building?"
"Oh, that's chromium."
"Well, what's chromium?"
"Why, it's a kind of nickel."

# BOOK REVIEWS

**Rohstoffprobleme der deutschen Aluminium-Industrie im Rahmen ihrer Wirtschaftlichen Entwicklung.** By Albrecht Czimatis. Paul Welzel, Dresden-Lockwitz, 1930. Paper, 5 1/2 × 8 1/4 inches, 126 pages.

The booklet presents an interesting survey of the raw material problem of the German aluminum industry from the introduction of the Hall-Heroult process until 1928. The subject is very capably discussed from both a practical and economic standpoint.

The first section describes the chief materials (aluminum ores, cryolite, carbon electrodes and electric power) necessary for the production of aluminum and the relative importance to the process. Some interesting figures on the carbon and power consumption per kilogram of reduced aluminum are given. Figures on the world production and consumption of aluminum and bauxite are also tabulated.

Aluminum ores and cryolite occur in only limited quantities in Germany. In the era before the war the German aluminum industry imported 95% of the total bauxite consumed from France. The World War complicated the raw material problem and lead to the development of Hungarian and Dalmatian bauxite deposits. The war also caused the introduction of synthetic cryolite.

The concluding sections described the raw material problem of the decade following the war. Bauxite is now imported from Hungary (42%), France (30%), Italy (16%), and Jugo-Slovakia (10%). Tables give the yearly bauxite tonnage imported by Germany from 1920 to 1928.

The booklet is supplemented by lists of the European aluminum plants and locations in 1918 and 1929.—Kent R. Van Horn.

**Werkstoff-Fragen des heutigen Dampfkesselbaues.** By Max Ulrich. Julius Springer, Berlin, 1930. Paper, 6 1/2 × 9 1/2 inches, 180 pages. Price 22.50 RM.

As a pioneer in the fields of research concerning boiler construction material, the author is well qualified to write this book, written to meet an urgent desideratum of peoples interested in the problems involved in boiler material. Progress in this field during the last decade was amazing and of a revolutionary character. Metallurgy shares in this progress to a large extent furnishing entirely new metals and alloys. Since progress is so rapid in this particular field, that books are out-of-date within a few years, we welcome the carefully selected material presented by Ulrich.

The subject is subdivided under the following headings: behavior of plain C-steel during tensile tests at room and at elevated temperatures, influence of time of load, consideration of aging, blue brittleness, changes in grain size due to recrystallization, alloyed boiler steels and their physical properties at ordinary and elevated temperatures, nature of cracks, working period until appearance of failures, numerical relationship between time in service and load, American conception on cause of failures of rivet seams, caustic embrittlement, conclusions and high pressure boilers: Atmos, Benson, Borsig, Humboldt, Löffler and Schmidt.

A special part of the book is devoted to researches made in America. The author, of course, endeavors to give a true picture of what is going on in the whole field covered by the book. He presents in the appendix a large number of references to German, American, English and French publications. The selection of illustrations and diagrams furnishing valuable data, is excellent. In contrast with standard text-books, such a special treatise necessarily includes data which are not fully confirmed. Due to its pioneering character, however, it must take into consideration the tendencies resulting from rapid development.—E. Fetz.

**Die Grundlagen des Walzens.** By Ernst Cotel. Verlag von Wilhelm Knapp, Halle (Saale), 1930. Paper, 6 1/2 × 9 1/4 inches, 99 pages. Price 6.60 RM

The author intended to write a book which would contain in a clear and simple manner the fundamental principles underlying the rolling process, and has succeeded in doing so. The book has 10 chapters which include explanations of rolling and the field of rolling, rolls and roll drawings, action of separating force on the rolls, reduction, elongation and spreading, forward slip, fundamental principles of roll pass design, design of the most commonly used passes, and roll train resistance.

Professor Cotel's book is a good compliation of the state of knowledge on the elementary theory of the rolling mill. Perhaps the greatest value of the book lies in the fact that Cotel has included some rather good abstracts from some works written in the Hungarian language. This fact is valuable because a good many more people in the United States can read technical German than can read technical Hungarian. The new data refer particularly to the flow of iron and steel in the rolling of flats, angle irons and channels.

More than 90% of the bibliography refers to papers written in the German language.

The book can be recommended as a good introduction to the theory of rolling and to the elementary methods of roll design.—W. Trinks.

**Handbuch der autogenen Metallbearbeitung.** By Theo. Kautny. Carl Marhold Verlagsbuchhandlung, Halle a. S., Germany, 1927. Paper, 5 × 7 inches, 825 pages. Price 22 RM.

Autogenous welding of metals has conquered such wide fields of application in the methods of working metals that a special treatment of it is fully justified. The author has, in the present compendium, been able to give a clear idea of the fundamentals of the method and to describe the various processes, the kind and purity of the gases employed, the preparation of the pieces, the different tools and equipment needed, and the shaping of certain objects. Also the physical changes occurring in the process, especially the expansion and the inner tensions produced thereby are fully treated.

The first chapter deals with the metals mostly used in the industries and gives in detail, figures and constants of their physical and chemical properties. In great detail the properties and characteristics of the various grades of steel and iron are discussed, and six pages are devoted to the composition of the numerous technically used copper alloys. The second chapter deals with the different methods to join metals mechanically and by autogenous processes and the third discusses the gases applied for autogenous welding with the equipment for compressed gases and the reduction of pressure for use. In the fourth chapter the methods of autogenous welding are described at length, while in the fifth the burners for welding and cutting are treated and manual and automatic equipment described and comparative costs given. In the sixth and last chapter, the technique of autogenous welding is exhaustively treated; emphasis is laid on the safety appliances and safety rules for the workmen to observe, handling of the equipment, preparation of working pieces with particular regard to interior stresses which have to be avoided. The production of small tubes is also described and the machinery for it; this chapter refers, however, more to the commercial sizes, the modern methods for welding large tubes is hardly touched as, of course, it hardly can be, these methods being kept more or less secret by the manufacturers. A very interesting paragraph is the one on the use of welding in ornamental iron working. A very good index and the many illustrations increase the usefulness of the book as a reference for many problems but the reviewer misses information with regard to testing the soundness of welded joints; this is of great importance and mention should have been made of some of the possibilities of magnetic tests and X-rays.—M. Hartenheim.

**Gusseisen, Eigenschaften und Prüfverfahren. Erfahrungen der Verbraucher.** (Report of Meeting of Technical Committee on Materials, Society of German Engineers, Oct. 28, 1929.) Verein deutscher Ingenieure Berlin. Paper 96 pages. Price 6 RM.

Contains 14 papers and discussions. Many subjects are briefly dealt with in this symposium, such as the properties of irons meeting different German specifications, relation of composition to machinability of cylinder iron, machinability in general, and influence of rate of cooling on structure and properties of test specimens.

Representatives of some 10 German firms told how they tested cast iron for different purposes.

The meeting was doubtless an interesting one to attend, but the papers are so brief that one does not get very much out of reading them.

H. W. G.

**Stahlbau.** By Otto Bondy. VDI Verlag G. m. b. H., Berlin, 1930. Cloth, 12 × 8 1/2 inches, 100 pages. Price 12 RM.

An excellently instructive selection of 100 welded constructions representative of the comparatively recent yet already widely used technique of welding. The present first volume shows buildings, crane runways and supports, roof constructions and trusses, hangars, pipe structures, bridges and many similar structures not only of German origin but example from the whole industrial world. The book is made up of single sheets or, rather, plates in a kind of loose-leaf arrangement and is supposed to be supplemented continually. The printing is very clear and fine on strong glazed paper. A short treatise on the calculation of welded joints precedes the book. After this first, one can look forward with great expectation to the following three volumes.—M. Hartenheim.

**Chemical Analysis of Special Steels.** By Charles Morris Johnson. John Wiley and Sons, Inc., New York, 1930. Cloth, 9 1/2 × 6 1/4 inches, 729 pages. Price $7.50.

The author points out in the preface to the fourth edition, that he has not undertaken a general revision, but has sought to bring the work up to date through the addition of eighteen appendices covering 176 pages. The added material which covers a wide range of subjects, contains nothing that is very new.

The arrangement is haphazard so that the appendices take on the nature of laboratory notes jotted down at random. Appendix III, for instance, takes up the determination of nickel in steel, and appears to cover the subject; appendix IV, in the midst of a discussion of copper and molybdenum, has a paragraph headed, "Nickel in Steel by Ferricyanide;" and appendix VIII comes along with more suggestions for nickel determination. There is much good material here, but the lack of a good consistent arrangement will militate against the book's being used as the laboratory handbook for which the author obviously intends it.

There is an attempt at extreme practicality in the stating of the exact number of washings which the different precipitates will require, and in the frequent introduction of time schedules showing the exact number of minutes to be allotted to each operation in the various determinations.

The book as a whole suffers from lack of clearness. The meaning is frequently obscured by grammatical errors and awkwardly constructed sentences. The author, furthermore, has a habit of departing from the simple chronological order in presenting the steps of a process. He will recall, as an after thought, in paragraph 2, something which could better have been stated explicitly in paragraph 1. All of which contributes to the confusion, and makes the book, not only unsafe as a laboratory guide in inexperienced hands, but uninteresting reading as a reference book.—M. P. Benoy.

**Tables for the Determination of Minerals.** By E. H. Kraus & W. F. Hunt. McGraw-Hill Book Co., New York, 1930. Cloth, 6 × 9 1/4 inches, 266 pages. Price $3.00.

This is a second edition of the widely used book published in 1911. As in the earlier edition, the bases of determination are the physical properties, characteristics and associates of the minerals. In this revision the tables are practically unchanged except that a few more minerals have been added, additional physical properties have been listed, and some extension made in the classification by colors. A useful table has been included giving the minerals in order according to specific gravity.—John Attwood.

**A.S.T.M. Tentative Standards—1930.** American Society for Testing Materials, Philadelphia. 864 pages, 6 × 9 inches. Price $8.00 cloth, $7.00 paper.

Among the 155 tentative specifications, methods of analysis and methods of testing are more than 30 dealing with ferrous and non-ferrous alloys. These cover track spikes, flange plates, boiler plates, cold-rolled strip, helical springs, locomotive forgings, cast steel anchor chain, manganese steel castings, steel pipe, chain link fencing, chilled car wheels, zinc coatings, fire-refined copper, duralumin sheet, Al-Mn sheet, Al alloys in castings and ingots, Mg alloy castings, copper base alloy ingots, 80 Cu 10 Sn 10 Pb castings, seamless Cu tubing, chemical analysis of Al and its alloys, of electrical resistors, tests for thermoelectric power, for thermal analysis, and for tension and compression testing, as well as specifications for Al powder and bronze powder for pigments, and definitions of terms relating to magnetic testing.—H. W. G.